ANL/NE-19/21

Theory Manual for the Fuel Cycle Analysis Code REBUS

Nuclear Science and Engineering Division

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March 30, 2020

ABSTRACT

REBUS is a system of programs designed for the fuel cycle analysis of fast reactors and accelerator-driven systems. The first version of REBUS was developed in 1970 for calculating the equilibrium operating conditions of liquid metal fast breeder reactors. During the past five decades, various extensions and refinements have been made in the simulation of material motions in fuel cycle facilities and the solution of the neutronics and isotopic transmutation equations that govern the reactor behavior. The latest version complies with the standard code practices and interface dataset specifications of the committee on computer code coordination (CCCC). This report provides a detailed description of the physical processes and their mathematical models and solution methods of the current production version of REBUS. The models of the facilities and physical processes involved in fast reactor fuel cycle are first discussed. Then the mathematical formulation of these physical models is presented, followed by detailed discussions of solution methods of the resulting set of equations. Finally the output edit quantities are discussed along with their definitions.

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1. Introduction

The primary purpose of this manual is to present a detailed description of the physical processes and their mathematical models and solution methods contained within the latest production version of the fast reactor fuel cycle analysis code REBUS of the Argonne Reactor Computation (ARC) system. The first version of REBUS (REactor BUrnup System) [1,2] was developed in 1970 based on the CYCLE code [3] for calculating the equilibrium operating conditions of liquid metal fast breeder reactors (LMFBRs). During the past five decades, various extensions and refinements have been made in the simulation of material motions in fuel cycle facilities and the solution of the neutronics and isotopic transmutation equations that govern the reactor behavior. With these enhanced modeling capabilities, REBUS has continuously been evolved into new versions, including the REBUS-2 [4,5] and REBUS-3 [6,7] codes. The latest version of REBUS released through the Radiation Safety Information Computational Center (RSICC) is the RSICC Code Package CCC-822, REBUS 11.2892 [8].

The REBUS code system provides for complete integration of the in-reactor and ex-reactor fuel cycle by combining a neutronics model and a fuel cycle model. The region-averaged group fluxes and the multiplication factor are the only interfaces to the fuel cycle model from the neutronics solution. The fuel cycle model does not involve any geometric information and thus allows the use of any static neutronics model (zero to three dimensional, diffusion or transport theory, deterministic or Monte Carlo solution). Currently, the finite-difference diffusion theory option DIF3D-FD [9], the nodal diffusion theory option DIF3D-Nodal [10], the variational nodal transport option DIF3D-VARIANT [11], and the discrete ordinate transport code TWODANT [12] are usable in the REBUS code system, although the diffusion theory codes DARC1D [13] and DARC2D [14] and the spatial flux synthesis code SYN3D [15] were used historically and the Monte Carlo code MCNP [16] is utilized in a version of REBUS named REBUS-PC [17]. DIF3D provides the flux solution in one-, two-, and three-dimensional problems of Cartesian, spherical, cylindrical, and triangular geometries. DIF3D-Nodal and DIF3D-VARIANT provide the flux solution in two- and three-dimensional Cartesian and hexagonal geometry problems. These three solvers are now integrated into the latest DIF3D 11.0 [18] and are embedded into REBUS and thus all of the standard features of DIF3D are usable in REBUS. TWODANT solves two-dimensional cylindrical-z problems and is called as an external executable from REBUS. In all of the flux solution options, there are no restrictions on the number of neutron energy groups, regions, or compositions.

The fuel cycle model of REBUS is divided into two main aspects: the simulation of material motions and the solution of the equation set governing the reactor behavior. The set of equations that govern the reactor behavior include isotopic transmutation and decay and reactivity control. Although limited, microscopic cross sections are permitted to vary as a function of the atom density of various reference isotopes in the problem as appropriate for soft spectrum systems. The user may specify axial control rod positions at each time node in the problem. Repetitive and non-repetitive fuel management schemes are available in REBUS, which permits in-reactor shuffling of fueled regions. A flexible scheme for the description of reprocessing and re-fabrication is also incorporated. REBUS provides a reprocessing plant model that considers fuel

discharge stream mixing and losses, fuel (re)fabrication with extensive external feed possibilities, and discharged fuel disposal with no restrictions on the number of external feeds, reprocessing plants, etc. The general non-repetitive fuel management capability also provides for temporary out-of-core storage, the loading of fresh fuel, and subsequent retrieval and reloading of the fuel.

REBUS solves two basic types of analysis problems: 1) the explicit cycle-by-cycle or non-equilibrium operation of a reactor under a specified periodic or non-periodic fuel management program; and 2) the infinite-time or equilibrium conditions of a reactor operating under a periodic fuel management scheme. For a basic non-equilibrium cycle problem, the depletion equations (i.e., coupled neutronics and isotopic transmutation equations) are solved for a user-specified initial core composition and fuel management scheme. The initial or charged fuel composition can be determined from external feeds according to the user-specified fabrication preference. Optionally, reprocessing may be included in the specification of the external fuel cycle and discharged fuel may be recycled back into the reactor.

An equilibrium cycle implies a reactor condition that is invariant for successive operation cycles under a fixed fuel management scheme and specific operating requirements. In other words, it is the limiting cycle attained after an infinite number of burn cycles. Although a real equilibrium cycle is not possible, near-equilibrium cycles can be achieved after a few transient cycles starting from the startup configuration by employing special fuel management procedures. The equilibrium cycle option has an important practical value when assessing the core performance of new reactors as it is a more valid basis than using an arbitrary sequence of startup cycles or constructing a complex fuel cycle that only considers one assembly shuffling pattern. The equilibrium solution can provide idealized estimates of the burn cycle time, control requirements, fuel enrichments, and general system performance characteristics at a lower overall computational cost than the explicit calculation of a proposed fuel management scheme. Having completed an equilibrium cycle calculation, the resulting parameters and partially burned fuel densities can be used as input to a detailed step-by-step, non-equilibrium cycle calculation in order to obtain specific operating characteristics of the reactor in its post-startup equilibrium state. Additionally, the equilibrium solution greatly facilitates the determination of the optimum new-reactor startup procedure [5]. In REBUS, the equilibrium cycle is mathematically formulated with the depletion equations under additional constraints for the nuclide densities, fuel burnup, and core reactivity.

For both non-equilibrium and equilibrium cycle problems, REBUS calculates the neutron flux, power, nuclide density, fluence, burnup, and conversion/breeding ratio distributions in the core and the associated mass flows among fuel cycle facilities as a function of time. A number of relational datasets containing various types of summary results are available for use in tailoring reports. In addition, four types of search procedures may be carried out in order to satisfy user-supplied constraints: 1) adjustment of the reactor burn cycle time to achieve a specified discharge burnup, 2) adjustment of the fresh fuel enrichment to achieve a specified

effective multiplication factor at a specified point during the burn cycle, 3) adjustment of the control poison density to maintain a specified value of the effective multiplication factor throughout the reactor burn cycle, and 4) adjustment of the reactor burn cycle time to achieve a specified value of the effective multiplication factor at the end of cycle (EOC).

In the early 2000s, the REBUS code was extended such that the analysis capabilities of critical reactor systems could be applied to a subcritical accelerator-driven system (ADS) [7]. This was achieved by modifying the depletion and charged fuel enrichment search parts of REBUS. The typical fuel depletion calculation is performed over a time step based upon the inputted power level. With an external source present, REBUS adjusts the source intensity to compensate for burnup reactivity loss during the irradiation cycle thereby achieving the desired power in each time step. The enrichment search capability was modified to ensure a desired (subcritical) multiplication factor of the inhomogeneous system is achieved at a specified point during the burn cycle. All three embedded solvers in DIF3D cannot model void regions such as the beam tube in ADS. Thus, to model the beam tube properly, the discrete ordinate transport code TWODANT [12] was interfaced with REBUS as an auxiliary neutronics solution option to DIF3D. Furthermore, the conversion ratio and reactor summary edits that are originally designed for breeder reactors were also extended for transuranic (TRU) burners with appropriate modifications to the output edits.

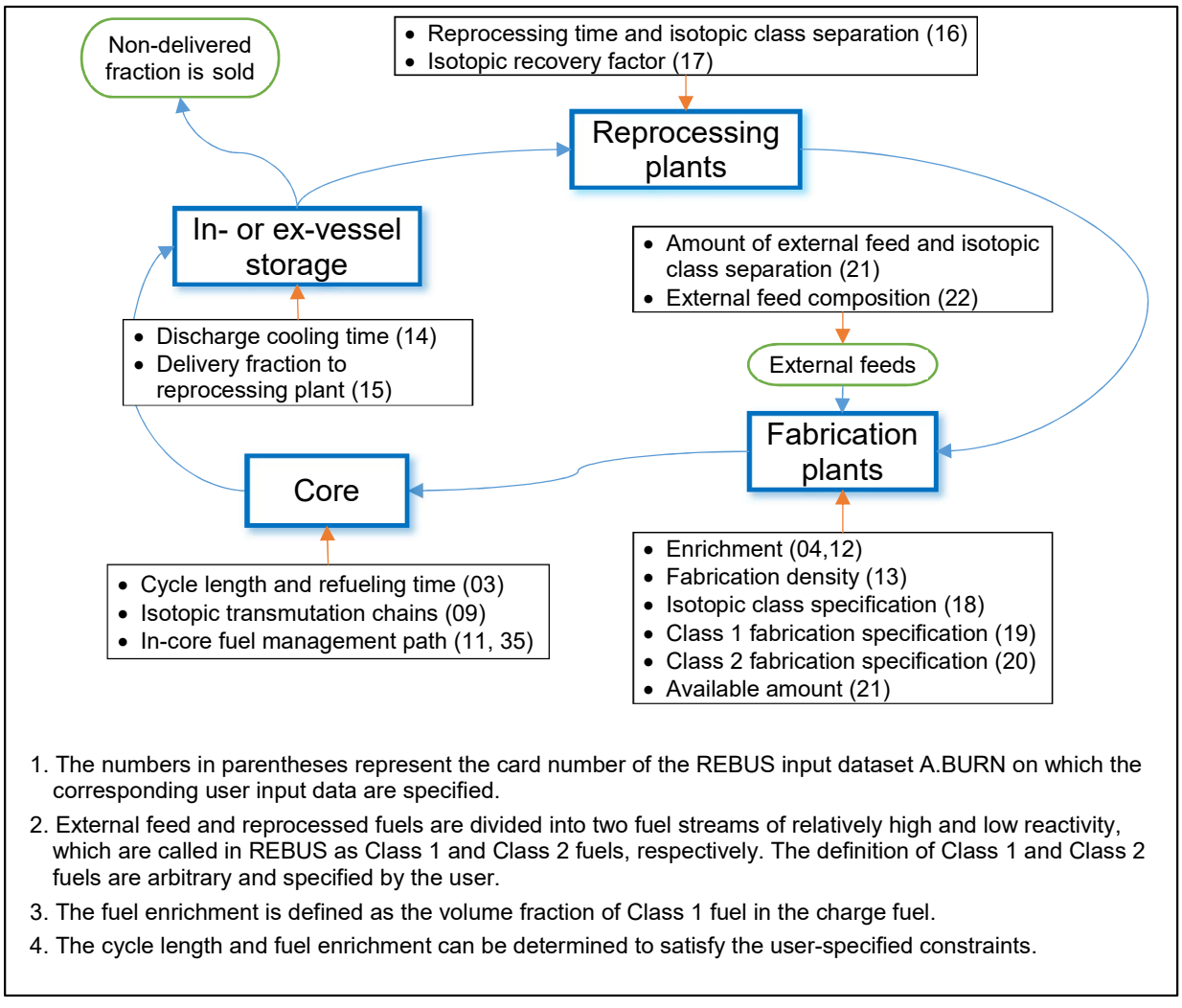
For the fresh fuel enrichment search problem of a critical reactor, the nuclide densities of partially burned fuels (which are called the stage densities in REBUS) are initially guessed equal to the fresh fuel densities corresponding to an assumed enrichment. With all fresh fuel, the initial multiplication factor is significantly higher than that of the actual burned fuel configuration and with iteration, REBUS arrives at the correct stage densities and multiplication factor. This approach does not work for a fixed source problem since it has a steady-state solution only when the system is subcritical. Therefore, the initial guess for the stage densities are determined by solving the same problem as an eigenvalue problem without the fixed source.

The rest of this report is organized as follows. Chapter 2 describes the various physical processes that form the fuel cycle models of REBUS. The in-reactor models for fuel management and depletion, and the ex-reactor models for fuel charge, discharge, reprocessing, re-fabrication, and external feeds are first discussed, focused on equilibrium cycle analysis. Then, the analysis models and methods peculiar to non-equilibrium cycle and subcritical ADS problems are described. Chapter 3 presents the mathematical formulation of the physical processes discussed in Chapter 2. The coupled system of nuclide transmutation equations and neutron transport equations is discussed first. This is followed by the description of the mathematical models for various in-reactor and ex-reactor processes. Then, the set of equations for single- and multi-cycle non-equilibrium problems and the boundary conditions and additional constraints for equilibrium cycle problems are discussed. Chapter 4 describes the methods to solve the equations discussed in Chapter 3. The solution methods for non-equilibrium fuel cycle problems are discussed first, focused on the region density iteration method to solve the coupled neutron and

nuclide field equations along with the matrix exponential method to solve the system of transmutation equations. The solution strategy for the equilibrium fuel cycle problem is then discussed. The specific sequence of iterative procedures to obtain the equilibrium solution are described. This is followed by the discussion on the algorithms for the charged fuel enrichment and cycle length search problems and the associated acceleration techniques. In Chapter 5, the output edits are discussed in detail with the mathematical formulas of output quantities.

2. Description of Physical Fuel Cycle Models

The fuel cycle model used in REBUS is subdivided into an in-reactor cycle and an ex-reactor or external cycle. Fig. 2.1 illustrates the REBUS models of major fuel cycle facilities. The in-reactor fuel cycle calculation involves fuel loading, shuffling and depletion. At the end of each cycle, some fuels may be discharged and fresh fuels can be loaded into the core. In this process, the burned fuels remaining in the core can be shuffled by carrying out a specified move sequence, which is specified as fuel management scheme. The external cycle model used in REBUS is intended to represent the actual course of events following the discharge of fuel from the reactor. Hence this ex-reactor model consists of the following successive steps: cooling, delivery to a reprocessing plant, re-fabrication using both reprocessed and external feed supplies, preloading storage, and reactor charge. Each of these phases will be described in more detail in the following sections.



1. The numbers in parentheses represent the card number of the REBUS input dataset A.BURN on which the corresponding user input data are specified.
2. External feed and reprocessed fuels are divided into two fuel streams of relatively high and low reactivity, which are called in REBUS as Class 1 and Class 2 fuels, respectively. The definition of Class 1 and Class 2 fuels are arbitrary and specified by the user.
3. The fuel enrichment is defined as the volume fraction of Class 1 fuel in the charge fuel.
4. The cycle length and fuel enrichment can be determined to satisfy the user-specified constraints.

Fig. 2.1. Illustration of REBUS Models of Major Fuel Cycle Facilities

These in-reactor and ex-reactor models are specified on the BCD (Binary Card-image Data) dataset A.BURN, which is the user specified input data for the fuel cycle model. In Fig. 2.1, the BCD card types of A.BURN used to provide the corresponding data are provided in parentheses.

The in-reactor model is coupled with the neutronics module through region-averaged group fluxes and the multiplication factor, and thus a REBUS calculation requires the input BCD datasets needed for flux calculation such as A.NIP3, A.DIF3D, and A.HMG4C. The general problem and edit specifications of REBUS are provided on the BCD dataset A.STP027.

In the following discussion, the specification of the in-reactor and external cycle models will be described and related to the corresponding card types of dataset A.BURN. The BCD input datasets A.STP027, A.BURN, and A.NIP3 are provided in Appendices A, B, and C, respectively.

2.1. In-Reactor Cycle Models

The in-reactor cycle is concerned with the location of each discrete fuel bundle or assembly in space and its isotopic densities over the period during which it resides in the reactor. For example, a bundle of certain specified composition may be loaded at a particular position, then irradiated for some specified time in a flux that is determined by the reactor configuration (i.e., spatial distribution of atomic densities) as well as the control and power requirements. After this initial burn, the bundle may or may not be repositioned in the reactor. In any case, if any of the fuel bundles in the reactor are moved, the irradiation rate will undergo a discontinuous change at the so-called fuel management or refueling time. After several burn/shuffle sequences, the bundle is discharged from the reactor.

In most of the REBUS documentation, the isotopic composition of a given fuel bundle is specified in terms of primary and secondary compositions. The primary and secondary compositions are respectively equivalent to the zone and sub-zone definitions specified by the Committee on Computer Code Coordination (CCCC) [19]. Thus in the remainder of this manual the isotopic content of a given part of the reactor geometry will be specified as either a zone or sub-zone. In REBUS, each fuel zone can be moved separately or several zones can be moved collectively. Either movement is defined through the *material type* discussed below and is constrained by the requirement of volume preservation. In-reactor movement of a single zone requires movement of at least two other zones. One zone must be moved from its position and inserted in another location or discharged from the reactor to make room for the original transfer. The space vacated by the original zone must be filled by fresh fuel or by a zone moved from another location. This linked sequence of fuel zone motions is referred to as a "fuel management path" since it describes the path that a specific zone takes through the reactor as a function of time.

In this section, the models and methods for the in-reactor fuel management and depletion calculation are discussed. To facilitate the discussion, the indexing system for in-reactor fuel identification and the fuel management schemes are described first. This is followed by the in-reactor cycle specifications, including the fuel management paths and isotopic transmutation chains.

2.1.1. Three-Level Indexing System for In-Reactor Fuel Identification

The fuel cycle module of the REBUS system identifies and locates each of the fuel bundles in the in-reactor cycle using three indices: *material type*, *stage*, and *region*. A given material type identifies all of those zones in the reactor that are following a specific fuel management path or sequence, which involves motion in both space and time. A material type is defined by its constituent atomic densities through the *primary* and *secondary* compositions specified with card type 14 of the neutronics input dataset A.NIP3. A primary composition (zone) is a mixture of isotopes and secondary compositions (sub-zones) while a secondary composition is a mixture of isotopes specified with card type 14 or materials specified with card type 13 of A.NIP3.

Because of neutron irradiation, the constituent atomic densities of a given material type are changing with time. Therefore, a material type that is placed in a specific spatial position at a given time is at a particular irradiation "stage" of its in-reactor history. A particular stage of a given material type is identified by the stage number. This stage number indexes the number of burn cycles applied to the material type. By convention, stage 1 represents the most recently charged fuel ("fresh" or unburned fuel if it is at the start of a burn cycle) while the highest stage number represents the material type that has been in the reactor the longest and therefore will be the one discharged at the next fuel management step.

The two indices material type and stage identify a fuel zone with respect to its in-reactor history. The two ends of the stage index sequence provide the link with the external cycle. As a specific illustrative example, suppose material type 7 consisted of four stages. There are therefore, four isotopically different definitions of material type 7, which may or may not be in different positions of the reactor at any given time point. The first stage is the freshly charged fuel, the second represents a fuel bundle which has gone through one burn cycle and therefore is characterized by a different set of isotopic densities from stage 1. Similarly, stages 3 and 4 have gone through 2 and 3 burn cycles, respectively. The stage 4 will be discharged at the fuel management step following the next burn cycle.

The final index "region" physically locates the specific fuel bundle in the reactor. A region is a closed volume over which the average group fluxes are calculated by the neutronics module being used. These space-dependent group fluxes are used in the isotopic transmutation or burnup calculations. A region may be as small as one neutronics mesh cell, but it is typically defined by an axial segment of a fuel assembly in order to account for the axial variation of transmutation rates within fuel assembly. Spatial regions are defined using the type 06 or 30 cards of the neutronics input dataset A.NIP3. The type 06 cards are used for orthogonal geometries (i.e., Cartesian, cylindrical, and spherical geometries), and the type 30 cards are used for triangular and hexagonal geometries.

The initial reactor configuration is specified by assigning zones to spatial regions with card 15 of A.NIP. If there are several different material types assigned to the same region, their isotopic content will be homogenized into a single region-averaged one for the neutronics

calculation. In order to treat this case, REBUS permits any number of material types to be placed in a single region provided that the total volume of all material types in a given region equals the physical region volume. Since a material type assigned to different locations in a core will likely have a different composition after the first irradiation stage, REBUS defines a unique zone for each depletion region after processing the user input data. Each unique zone is defined with the region label and the user-specified zone composition.

A zone that is assigned to a region at a particular time point may be moved at a later time point and replaced by another zone. Depending upon the type of calculation being executed, this movement is carried out by changing the sub-zone assignment to region (and thereby sub-zone to zone assignment), the sub-zone assignment to zone, or the zone assignment to region. Therefore, for a REBUS calculation both zone and sub-zones must be defined via the A.NIP3 input for every depleting zone. Note that each zone should have at most one sub-zone assigned to it. The fuel management paths or sequences are defined using card type 11 or card type 35 of A.BURN as discussed below in Section 2.1.3. Card type 11 is used for repetitive fuel management schemes while card type 35 is used for general non-repetitive fuel management schemes.

If the fresh fuel isotopic content of all material types are held constant and the burn/refuel process is repeated, the isotopic of the discharged fuel bundles will approach constant values as time increases, assuming that control and criticality constraints are not violated. This reactor condition is actually calculated (or approximated) in one step when solving an equilibrium recycle problem. The solution methods to the equilibrium cycle problem are detailed in Chapter 4.

2.1.2. Fuel Management Schemes

At the end of each cycle, some fuels may be discharged and fresh fuels can be loaded into the core. In this process, the burned fuels remaining in the core can be shuffled by carrying out a specified move sequence. Two possibilities arise in the case that fuel management procedures change after a burn cycle. The first one is a non-repetitive fuel management scheme where a particular move sequence is to be carried out only once. Therefore, each fuel bundle in the reactor must be accounted for separately at the end of each burn cycle. Clearly no equilibrium condition can be defined for this case. This non-repetitive fuel management scheme is specified using card type 35 of A.BURN, and it permits completely general in-reactor shuffling of fuel bundles including temporary out-of-core storage, loading of fresh fuel, and subsequent retrieval and reloading of the fuel.

The second one is the repetitive fuel management scheme specified with card type 11 of A.BURN. There exist two different types of repetitive fuel management schemes. One is a scattered reloading without shuffling and the other is a repetitive fuel reloading with shuffling. In the scattered reloading scheme, often employed in liquid metal cooled fast reactors to reduce the risk of misplacing or dropping fuel assemblies in the opaque coolant, a number of burn cycles

elapse without any fuel movement for a particular material type, then one discharge-charge move is made, and so on with a fixed repetition factor. This fuel management scheme is repetitive and thus can lead to an equilibrium condition.

An illustrative example of a 3-batch scatter loading is shown in Fig. 2.2. Here "CR" denotes a control assembly, and "Rmnn" is the region label for the *nn*-th hexagon of the *m*-th hexagonal ring. (The order of rings and hexagons in the rings follow the convention of the type 30 cards of A.NIP3 used for the specification of regions in hexagonal geometries.) The characters "A" to "F" represent potentially different material types, and the numbers in parentheses are the stage numbers at the beginning of each cycle. In this example, all the fuel assemblies reside in the reactor for three cycles without any movement. At the end of each cycle, the assemblies of stage 3 are discharged. Then fresh assemblies of stage 1 are loaded into the vacated positions and stay in the same position until they are discharged after three cycles. After a sufficient number of cycles, the reactor will approach an equilibrium condition where the reactor configuration is repeated with a period of three cycles.

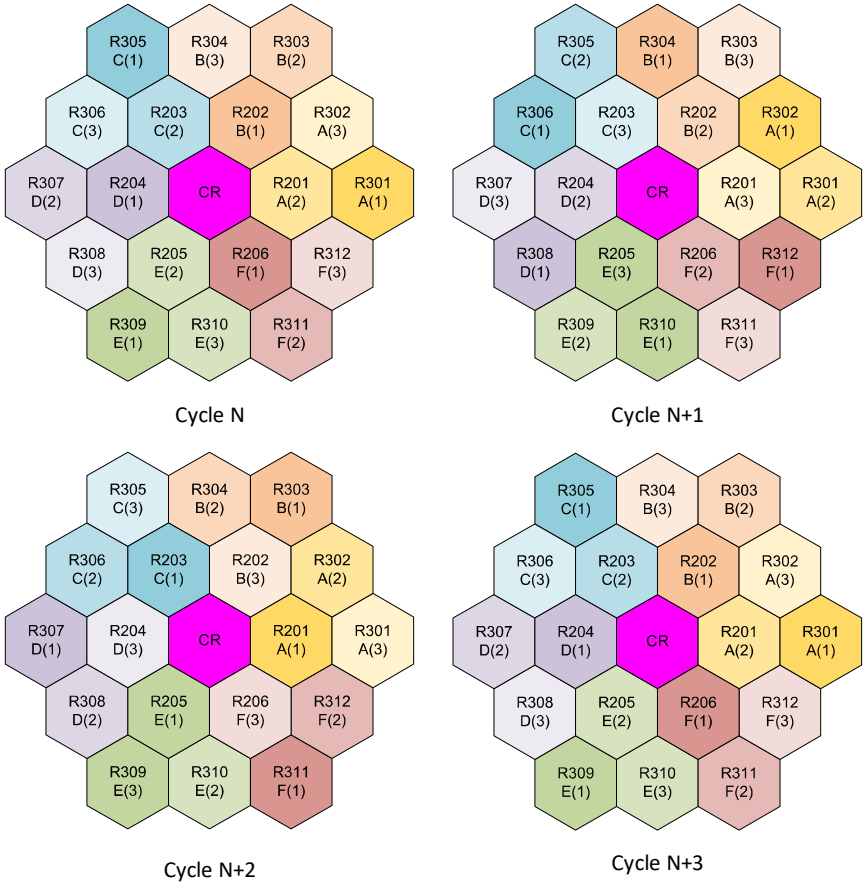


Fig. 2.2. Illustrative Example of 3-Batch Scattered Reloading Scheme

The amount of numerical work required for each pass toward the equilibrium solution is equal to that for a single burn cycle multiplied by the least common multiple of the repetition

factors of all the material types in the reactor. In the above example in Fig. 2.2, a three cycle problem needs to be solved repetitively to obtain the equilibrium condition. In order to enhance the computational efficiency, REBUS uses an alternative solution scheme. It calculates the batch-averaged equilibrium condition of the reactor over a number of cycles that is the least common factor of the repetition factors for all materials in the reactor. In this modified problem averaged over cycles, each region would contain the mixture of N_s compositions of stages 1 through N_s, where N_s is the number of stages of the assigned material type, which is equal to the repetition factor of that material. In other words, it is assumed that the fuels of stages 1 through N_s coexist in each region with the equal volume fraction as illustrated in Fig. 2.3 for the example in Fig. 2.2. Because of the long mean free paths of neutrons in fast reactors, this homogenization can approximate the scattered reloading very well. In addition, the same fuel management procedure can be carried out at the end of every burn cycle by replacing the composition of stage N_s with the fresh composition of stage 1, as discussed below in Section 2.1.3. The sequence of stages of a material type present in the reactor at any time represent different phases in the burnup history of a fuel bundle since the fuel management procedure is held fixed. Hence the equilibrium solution can be obtained by calculating only one burn cycle iteratively.

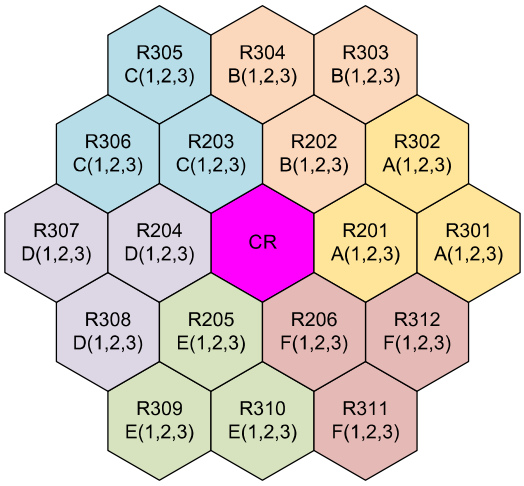


Fig. 2.3. Batch-Averaged Configuration of the 3-Batch Scattered Reloading in Fig. 2.2

In the repetitive reloading scheme with shuffling, fuel is shuffled at the end of each cycle by carrying out the specified move sequence repeatedly. After a sufficient number of cycles, the reactor will approach an equilibrium condition with a repetition factor of one. As an illustrative example, Fig. 2.4 shows the reactor configuration at BOC for a repetitive 3-batch reloading scheme with shuffling. This reactor configuration is the same as the cycle *N* configuration in Fig. 2.2, but fuels are moved such that every cycle has the same configuration. For example, consider the material type "A." At the beginning of cycle *N*, the regions R301, R201, and R302 contain the fuels of stages 1, 2, and 3, respectively. During a burn cycle, the stage numbers are increased by one, and thus at the end of cycle *N*, the fuels in the regions R301, R201, and R302 become once-burned (stage 2), twice-burned (stage 3), and thrice-burned (stage 4), respectively. It is

noted that if a fuel management path has N_s stages, a discharge label for this path is defined as the N_s+1 stage on the card type 11 of A.BURN. The stage 4 fuel in R302 is discharged, and then the stage 3 fuel in R201 is moved to R302. Subsequently, the stage 2 fuel in R301 is moved to R201, and a fresh fuel of stage 1 is charged into R301. Therefore, at the beginning of the cycle N+1, the regions R301, R201, and R302 contain the fuels of stages 1, 2, and 3, respectively, as in the cycle N. After a sufficient number of cycles, the stage compositions will approach the equilibrium compositions and thus the reactor will approach an equilibrium condition where the reactor configuration is repeated every cycle.

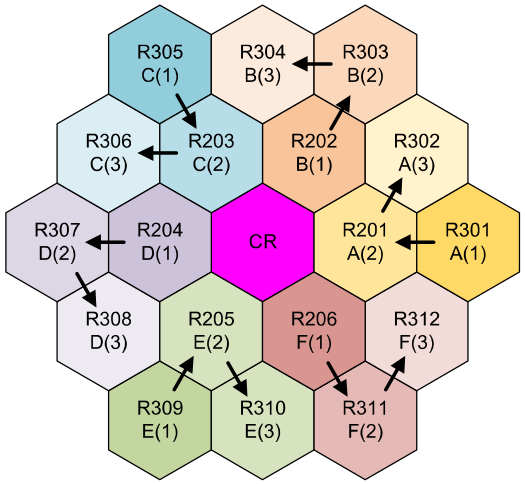


Fig. 2.4. Illustrative Example of Repetitive 3-Batch Reloading Scheme with Shuffling

The repetitive fuel management scheme defined on the type 11 cards of A.BURN can include fuel movement for a non-equilibrium problem. Therefore, an explicit cycle-by-cycle condition of reactor can be determined for a non-equilibrium cycle problem under a specified repetitive or non-repetitive fuel management scheme with fuel shuffling. It is also noted that individual fuel zones can be accounted for separately at the end of each burn cycle through direct reference to the index triplet (material type, stage, and region). As a result, in a simple non-equilibrium problem in which a different fuel management procedure is carried out after each burn cycle, the stage index is redundant.

2.1.3. In-Reactor Cycle Specifications

As mentioned in the introduction, REBUS solves two basic types of analysis problems: 1) the non-equilibrium operation of a reactor under a specified periodic or non-periodic fuel management program; and 2) the equilibrium conditions of a reactor operating under a periodic fuel management scheme. The selection of equilibrium or non-equilibrium problem is specified on the card type 01 of A.STP027 along with other problem options. Various output edit specifications are also provided with the A.STP027 input. All of the other in-reactor cycle

specification data are given through the fuel cycle input dataset A.BURN while geometry and composition details are provided via A.NIP3.

The simplest type of problem is the non-equilibrium type problem in which the user specifies a fully-loaded reactor (with no information about the external cycle) to be operated at a specified power level for the specified burn cycle time. The initial reactor configuration is specified using card types 14 and 15 in A.NIP3. As mentioned in Section 2.1.1, all zone and sub-zones are defined with card types 13 and 14 and assigned to the core regions with the card type 15. The steady state reactor power is specified on card type 06 of the A.DIF3D input. The burn cycle length is specified on card type 03 of A.BURN or optionally via card type 36.

The depletion calculation can be performed with or without the use of time subintervals (to improve the accuracy of the depletion calculation for long burn cycle times). The shutdown time and length of each burn cycle are specified on the type 03 card of A.BURN, and modified as desired using the card type 36. The number of subintervals into which the total burn cycle time is to be divided is also specified on the type 03 card. Flux distributions are calculated at time zero and at the end of each time subinterval. Each point is called a time node. Thus a problem with N subintervals has N+1 time points. For non-equilibrium problems, there is no limit to this number, while for equilibrium problems it is limited to a maximum of four subintervals. Non regular subinterval time steps can also be specified with card type 47.

Optionally, one can specify a fuel management program to follow after any number of burn/shutdown/shuffle cycles. The total number of fuel management operations is also specified on the type 03 card. The last fuel management operation is then followed by a final burn step such that the total number of burn cycles to be computed is always one more than the number of fuel management operations specified. The required fuel management paths are defined with card type 11 or 35 of A.BURN. The transmutation chains for depletion calculation are defined with card types 09 and 25. The isotropic multi-group cross sections in each region can be identified through the equivalent isotope labels listed on card type 10. Burnup-dependent cross sections can also be specified using card type 26 and 39-41. By identifying control materials with card types 21 to 23 in A.NIP3, control searches may be carried out to maintain a prescribed multiplication factor at each time node. Time-dependent control rod positions can also be specified on the type 38 cards which typically require iterative adjustment and execution by the user to achieve the same behavior at each time node.

REBUS has a search capability to determine the charged fuel enrichment and the cycle length to satisfy the user-specified operating conditions. Specifically, the fresh fuel enrichment can be adjusted to achieve a specified effective multiplication factor at any selected time point of the burn cycle. Alternatively, the reactor burn cycle time can also be adjusted to obey a specified discharge burnup limit or obtain a specified value of the effective multiplication factor at EOC. For these problems, the initial guesses of the search parameter need to be provided along with the convergence criteria. For the charged fuel enrichment search, the external cycle needs to be

specified as well. A description of the external cycle is given below in Section 2.2 with a discussion of the associated input needed to specify each aspect of the cycle.

The enrichment search capability applies to non-equilibrium cycle problems as well as equilibrium cycle problems, but must include input defining fuel fabrication and all paths must specify a fuel discharge process. The user can specify a repetitive fuel shuffling scenario or use the scattered loading concept without explicit fuel shuffling. A repetitive fuel management scheme specified with card type 11 of A.BURN is applicable with the enrichment search while card type 35, general fuel management, cannot be used.

The A.BURN cards are not organized according to their functional groups as the software was modified over a 50 year period with a strong focus on backward compatibility. As a simple guide, the required and optional cards of A.BURN for each function are summarized in Table 2.1. For a non-equilibrium cycle problem, the basic input data are required and the other input data are optional depending on the actual use. An equilibrium cycle problem requires the input data for enrichment search and/or cycle length search in addition to the basic input data, except for card type 35 used for non-equilibrium cycle fuel management only. In the following section, the transmutation chains, fuel management paths, and burnup dependent cross sections are discussed.

Table 2.1. Functional Groups of A.BURN Cards

Functions		Required	Optional
Basic non-equilibrium cycle analysis	Problem definitions	03	01, 02, 47
	Transmutation chains	09	10, 25
	Fuel management paths	11 or 35	36, 37,45
	Active isotope data	24	
Enrichment search	Initial guess and convergence criteria	04	
	Required external cycle	12, 13, 18-22	
Cycle length search	Burnup limits	06	05, 07, 08
	k-effective at EOC	27	
Reprocessing	Basic equilibrium cycle	15, 16, 17	14, 23
	Non-equilibrium cycle	42, 43, 44	
Others	Burnup-dependent XS	26, 39, 40, 41	
	Time-dependent control rod positions	38	
	User-defined conversion ratios		46
	Summary edits		29-34

Specification of Isotopic Transmutation Chains

The isotopic transmutation rate matrix used in REBUS may contain β^-, β^+, α, and up to 9 arbitrary decay processes as well as (n,γ), (n,p), (n,α), (n,2n), (n,d), (n,t), and (n,f) reactions. Additionally, any number of fission products are permitted with fractional yields that are isotope dependent. For decay reactions, isomeric-state branching factors are also permitted for each decaying isotope. Which isotopes appear in a calculation, and the reactions that they undergo, are specified using card types 09, 24 and 25 of A.BURN. All the isotopes listed on card type 09 are termed "active" isotopes in that their atomic densities will change as a function of time as the reactor is operated. The isotopes not included on card type 09 are "inactive" isotopes of which nuclide densities do not change with time such as those in coolant and structural materials. At least one of the active isotopes must appear on card type 24. It should be noted that the computer memory required by REBUS scales linearly by the number of fissionable zones and the square of the number of active isotopes. The DIF3D memory requirements normally dwarf those of REBUS.

A sample set of transmutation chains used for EBR-II analyses is shown in Fig. 2.5. Here the symbols ⓐ to ⓖ are the connecting points of the lines broken into the upper and lower figures. The nuclides denoted by yellow boxes are the important nuclides explicitly included in transmutation chains. The nuclides denoted by white boxes are the short-lived intermediate product nuclides that are typically assumed to decay instantaneously in order to improve the computational efficiency and numerical stability. Thus it is recommended not to include such isotopes in the transmutation chain noting that REBUS allows the user to setup the depletion chain as desired. The nuclides of pink or red color are typically produced in miniscule quantities and are represented with fictitious dummy nuclides in order to truncate the transmutation chains. The dummy nuclides are assumed not to react at all such that the cross sections are set to zero. What is important with this approach is that the dummy isotope production is tracked thereby allowing the user to verify it is insignificant.

In Fig. 2.5, some reactions yield multiple nuclides as is the case for ^{236}Np, ^{242}Am, and ^{243}Am. The (n,2n) reaction of ^{237}Np yields ^{236}Np 28% of the time and the metastable state of ^{236}Np 72% of the time. Similarly, the (n,γ) reaction of ^{241}Am and (n,2n) reaction of ^{243}Am yield two other isotopes. Table 2.2 compactly summarizes the branching ratios and half-lives of the nuclides included in Fig. 2.5 where EC(ε) represents electron capture. The branching ratios depend upon the incident neutron energy as displayed in Fig. 2.6, and thus the effective branching ratios should be determined with the appropriate spectrum weighting. Radioactive decays can also include multiple decay modes, yielding multiple product nuclides.

The reduced transmutation chains where the short-lived intermediate nuclides are excluded are presented in Table 2.3. For example, the capture reaction of ^{241}Am is modeled to yield ^{242}Cm, ^{242m}Am, and ^{242}Pu directly with the yield fractions of 0.66, 0.20, and 0.14, respectively. The products of (n,2n) reactions of ^{238}Pu and ^{241}Am are represented by ^{237}Np and ^{240}Pu, respectively.

The (n,2n) reaction of ^{243}Am is assumed to yield ^{242m}Am, ^{242}Pu, and ^{242}Cm with the yield fractions of 0.5, 0.086, and 0.414, respectively. ^{242}Cm is assumed to yield ^{241}Am in 99% of its (n,2n) reactions and ^{237}Np in 1%. It is assumed that 37.4% of the (n,2n) reactions of ^{237}Np yield

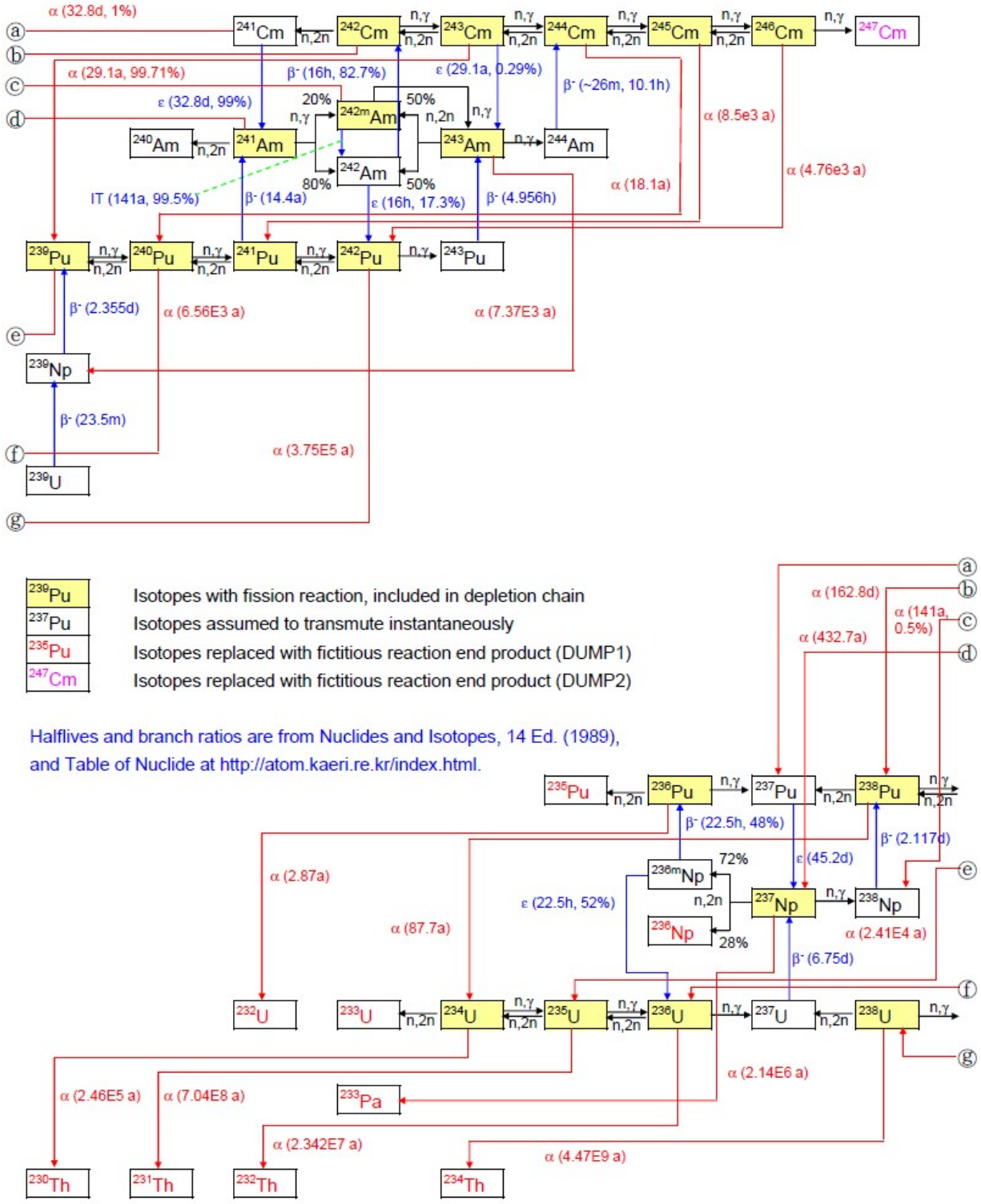


Fig. 2.5. Transmutation Chains Used in EBR-II Analyses

Table 2.2. Branching Ratios and Half-lives of Important Actinides

Isotope	Reaction	Product Isotopes	Branching Ratio	Half-life	
^{234}U	α	^{230}Th		2.45E+05	year
^{235}U	α	^{231}Th		7.04E+08	year
^{236}U	α	^{232}Th		2.34E+07	year
^{237}U	β$^-$	^{237}Np		6.75	day
^{238}U	α	^{234}Th		4.47E+09	year
^{239}U	β$^-$	^{239}Pu		23.5	minute
^{236m}Np	β$^-$	^{236}Pu	0.48	22.5	minute
	EC (ε)	^{236}U	0.52		
^{237}Np	n,2n	^{236m}Np	0.72		
		^{236}Np	0.28		
	α	^{233}Pa		2.14E+06	year
^{238}Np	β$^-$	^{238}Pu		2.12	day
^{239}Np	β$^-$	^{239}Pu		2.355	day
^{236}Pu	α	^{232}U		2.87	year
^{238}Pu	α	^{234}U		87.7	year
^{239}Pu	α	^{235}U		2.41E+04	year
^{240}Pu	α	^{236}U		6.55E+03	year
^{241}Pu	β$^-$	^{241}Am		14.4	year
^{242}Pu	α	^{238}U		37.5	year
^{243}Pu	β$^-$	^{243}Am		4.956	hour
^{241}Am	n,γ	^{242m}Am	0.2		
		^{242}Am	0.8		
	α	^{237}Np		432.7	year
^{242}Am	β$^-$	^{242}Cm	0.827	16	hour
	EC (ε)	^{242}Pu	0.173		
^{242m}Am	α	^{238}Np	0.005	141	year
	IT	^{242}Am	0.995		
^{243}Am	n,2n	^{242m}Am	0.5		
		^{242}Am	0.5		
	α	^{239}Np		7.37E+03	year
^{244}Am	β$^-$	^{244}Cm		10.1	hour
^{241}Cm	α	^{237}Np	0.01	32.8	day
	EC (ε)	^{241}Am	0.99		
^{242}Cm	n,2n	^{241}Cm			
	α	^{238}Pu		162.8	day
^{243}Cm	α	^{239}Pu	0.9974	28.5	year
	EC (ε)	^{243}Am	0.0026		
^{244}Cm	α	^{240}Pu		18.1	year
^{245}Cm	α	^{241}Pu		8.47E+03	year
^{246}Cm	α	^{242}Pu		4.73E+03	year

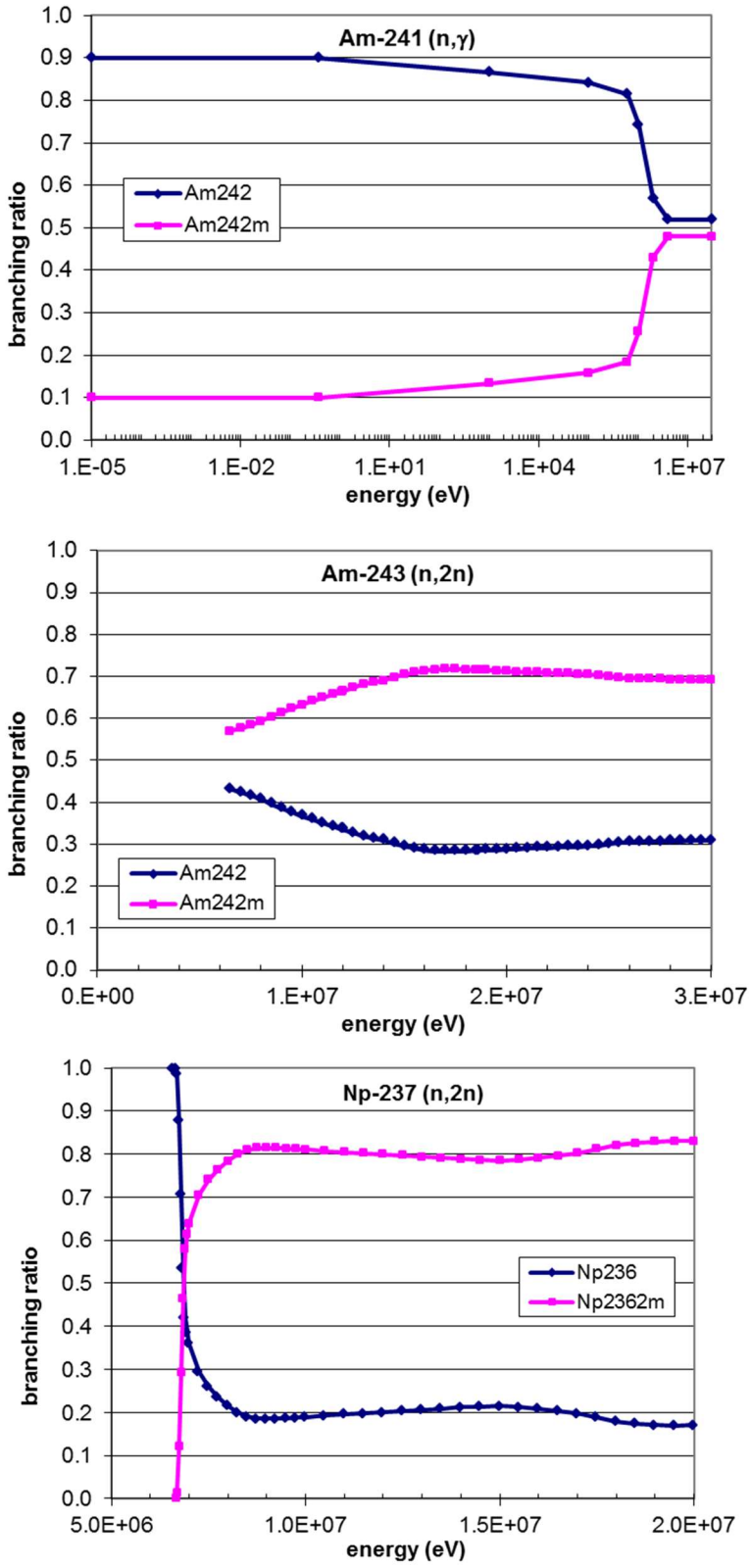


Fig. 2.6. Branching Ratios of ^{241}Am (n,γ), ^{243}Am (n,2n), and ^{237}Np (n,2n) Reactions

Table 2.3. Branching Ratios of Reduced Transmutation Chains Used in EBR-II Analyses

Isotope	Reaction	Product Isotopes	Branching Ratio	Decay Constant (s^{-1})	Remarks
^{237}Np	n,2n	^{236}Np	0.280		DUMP1
		^{236}Pu	0.346		0.72×0.48
		^{236}U	0.374		0.72×0.52
^{241}Am	n,γ	^{242m}Am	0.200		
		^{242}Cm	0.662		0.8×0.827
		^{242}Pu	0.138		0.8×0.173
^{242m}Am	α	^{238}Pu	1.000	7.225E-13	λ×0.005
	β^-	^{242}Cm	1.000	1.189E-10	λ×0.995×0.827
	EC (ε)	^{242}Pu	1.000	2.487E-11	λ×0.995×0.173
^{243}Am	n,2n	^{242m}Am	0.500		
		^{242}Cm	0.414		0.5×0.827
		^{242}Pu	0.087		0.5×0.173
^{242}Cm	n,2n	^{237}Np	0.010		1.0×0.01
		^{241}Am	0.990		1.0×0.99
^{243}Cm	α	^{239}Pu	1.000	7.685E-10	λ×0.9971
	EC (ε)	^{243}Am	1.000	2.003E-12	λ×0.0029

^{236}U and the remaining 62.6% yield a fictitious dummy isotope. The products of ^{248}Cm (n,γ) and ^{232}U (n,2n) reactions are represented by a fictitious dummy isotope. The way to determine the branching ratios and decay constants seen in the reduced transmutation chains is provided in the rightmost column of Table 2.3.

REBUS has four pre-stored sets of transmutation chains: PUUCH1, THUCH1, PUUCH2, and THUCH2. PUUCH1 and THUCH1 correspond to simple plutonium-uranium (PU-U) and thorium-uranium (TH-U) chains, respectively, and PUUCH2 and THUCH2 are complex PU-U and TH-U chains, respectively. The transmutation chains of PUUCH1, THUCH1, PUUCH2, and THUCH2 are summarized in Table 2.4 through Table 2.7, respectively. In these tables, LFPP3, LFPP5, LFPP9, and LFPPA are lumped fission products (LFPs), which depend on fissioning nuclides. DUMP1 and DUMP2 are dummy isotopes used to replace unimportant nuclides in order to terminate the transmutation chains. The LFPs and the dummy nuclides are assumed not to react further. It is noted that the LFPs have non-zero cross sections and included in neutronics calculations, whereas the dummy nuclides have zero cross sections.

The user may specify one of these pre-stored chains than the normal procedure of using the type 09 cards to indicate the components of the chains. This can be done by using one of the privileged burn chain labels instead of the isotope label in columns 7-12 of the type 09 card of A.BURN.

The user may also add to or delete parts of the pre-stored chains as described in the card type 09 and 25 descriptions of A.BURN included in Appendix B.

Table 2.4. Pre-stored Simple Transmutation Chain PUUCH1

Isotope	Reaction	Product Isotopes	Decay Const. (s^{-1})	Isotope	Reaction	Product Isotopes	Decay Const. (s^{-1})
^{235}U	n,γ	^{236}U		^{240}Pu	n,γ	^{241}Pu	
	n,f	LFPP5			n,f	LFPP9	
^{236}U	n,γ	DUMP1		^{241}Pu	n,γ	^{242}Pu	
	n,f	LFPP3			n,f	LFPP9	
^{238}U	n,γ	^{239}Pu			β^-	DUMP1	1.4952E-9
	n,f	LFPP9		^{242}Pu	n,γ	DUMP1	
^{238}Pu	n,γ	^{239}Pu			n,f	LFPP9	
	n,f	LFPP9		LFPP3	No reaction		
^{239}Pu	n,γ	^{240}Pu		LFPP5	No reaction		
	n,f	LFPP9		LFPP9	No reaction		
	(n,2n)	^{238}Pu		DUMP1	No reaction		

Table 2.5. Pre-stored Simple Transmutation Chain THUCH1

Isotope	Reaction	Product Isotopes	Decay Const. (s^{-1})	Isotope	Reaction	Product Isotopes	Decay Const. (s^{-1})
^{232}Th	n,γ	^{233}Pa		^{238}Pu	n,γ	^{239}Pu	
	n,f	LFPP3			n,f	LFPP9	
^{233}Pa	n,γ	^{234}U		^{239}Pu	n,γ	^{240}Pu	
	n,f	LFPP3			n,f	LFPP9	
	β^-	^{233}U	2.9713E-7		(n,2n)	^{238}Pu	
^{233}U	n,γ	^{234}U		^{240}Pu	n,γ	^{241}Pu	
	n,f	LFPP3			n,f	LFPP9	
^{234}U	n,γ	^{235}U		^{241}Pu	n,γ	^{242}Pu	
	n,f	LFPP3			n,f	LFPP9	
^{235}U	n,γ	^{236}U			β^-	DUMP1	1.4952E-9
	n,f	LFPP5		^{242}Pu	n,γ	DUMP1	
^{236}U	n,γ	DUMP1		LFPP3	No reaction		
	n,f	LFPP3		LFPP5	No reaction		
^{238}U	n,γ	^{239}Pu		LFPP9	No reaction		
	n,f	LFPP9		DUMP1	No reaction		

Table 2.6. Pre-stored Complex Transmutation Chain PUUCH2

Isotope	React.	Product Isotopes	BR	Decay Const. (s^{-1})	Isotope	React.	Product Isotopes	BR	Decay Const. (s^{-1})
^{234}U	n,γ	^{235}U			^{241}Am	n,γ	^{242}Cm	0.66	
	n,f	LFPP3					^{242}Am	0.20	
^{235}U	n,γ	^{236}U					^{242}Pu	0.14	
	n,f	LFPP5				n,f	LFPPA		
^{236}U	n,γ	^{237}Np			^{242}Am	n,γ	^{243}Am		
	n,f	LFPP3				n,f	LFPPA		
^{238}U	n,γ	^{239}Pu			^{243}Am	n,γ	^{243}Cm		
	n,f	LFPP9				n,f	LFPPA		
	n,2n	^{237}Np			^{242}Cm	n,γ	^{243}Cm		
^{237}Np	n,γ	^{238}Pu				n,f	LFPPA		
	n,f	LFPPA				α	^{238}Pu		4.9278E-8
	n,2n	^{236}Pu	0.36		^{243}Cm	n,γ	^{244}Cm		
		^{236}U	0.36			n,f	LFPPA		
		DUMP1	0.28			α	^{239}Pu		7.86433E-10
^{236}Pu	n,f	LFPPA			^{244}Cm	n,γ	^{245}Cm		
	α	DUMP1		7.7121E-9		n,f	LFPPA		
^{238}Pu	n,γ	^{239}Pu				α	^{240}Pu		1.23018E-9
	n,f	LFP99			^{245}Cm	n,γ	^{246}Cm		
	α	^{234}U		2.5022E-10		n,f	LFPPA		
^{239}Pu	n,γ	^{240}Pu			^{246}Cm	n,γ	DUMP2		
	n,f	LFPP9				n,f	LFPPA		
	n,2n	^{238}Pu			LFPP3	No reaction			
^{240}Pu	n,γ	^{241}Pu			LFPP5	No reaction			
	n,f	LFPP9			LFPP9	No reaction			
^{241}Pu	n,γ	^{242}Pu			LFPPA	No reaction			
	n,f	LFPP9			DUMP1	No reaction			
	β$^-$	^{241}Am		1.4952E-9	DUMP2	No reaction			
^{242}Pu	n,γ	^{243}Am							
	n,f	LFPP9							

Table 2.7. Pre-stored Complex Transmutation Chain THUCH2

Isotope	React.	Product Isotopes	BR	Decay Const. (s^{-1})	Isotope	React.	Product Isotopes	BR	Decay Const. (s^{-1})
^{232}Th	n,γ	^{233}Pa			^{241}Pu	n,γ	^{242}Pu		
	n,f	LFPP3				n,f	LFPP9		
^{233}Pa	n,γ	^{234}U				β-	^{241}Am		1.4952E-9
	n,f	LFPP3			^{242}Pu	n,γ	^{243}Am		
	β-	^{233}U		2.9713E-7		n,f	LFPP9		
^{233}U	n,γ	^{234}U			^{241}Am	n,γ	^{242}Cm	0.66	
	n,f	LFPP3					^{242}Am	0.20	
^{234}U	n,γ	^{235}U					^{242}Pu	0.14	
	n,f	LFPP3				n,f	LFPPA		
^{235}U	n,γ	^{236}U			^{242}Am	n,γ	^{243}Am		
	n,f	LFPP5				n,f	LFPPA		
^{236}U	n,γ	^{237}Np			^{243}Am	n,γ	^{243}Cm		
	n,f	LFPP3				n,f	LFPPA		
^{238}U	n,γ	^{239}Pu			^{242}Cm	n,γ	^{243}Cm		
	n,f	LFPP9				n,f	LFPPA		
	n,2n	^{237}Np				α	^{238}Pu		4.9278E-8
^{237}Np	n,γ	^{238}Pu			^{243}Cm	n,γ	^{244}Cm		
	n,f	LFPPA				n,f	LFPPA		
	n,2n	^{236}Pu	0.36			α	^{239}Pu		7.86433E-10
		^{236}U	0.36		^{244}Cm	n,γ	^{245}Cm		
		DUMP1	0.28			n,f	LFPPA		
^{236}Pu	n,f	LFPPA				α	^{240}Pu		1.23018E-9
	α	DUMP1		7.7121E-9	^{245}Cm	n,γ	^{246}Cm		
^{238}Pu	n,γ	^{239}Pu				n,f	LFPPA		
	n,f	LFP99			^{246}Cm	n,γ	DUMP2		
	α	^{234}U		2.5022E-10		n,f	LFPPA		
^{239}Pu	n,γ	^{240}Pu			LFPP3	No reaction			
	n,f	LFPP9			LFPP5	No reaction			
	n,2n	^{238}Pu			LFPP9	No reaction			
^{240}Pu	n,γ	^{241}Pu			LFPPA	No reaction			
	n,f	LFPP9			DUMP1	No reaction			
					DUMP2	No reaction			

The reactivity effects of fission products are relatively small and thus they can be represented by lumped fission products (LFPs). For thermal spectrum systems, however, several tens of individual fission products are explicitly modeled by specifying them with card type 09 of A.BURN. Since the yields of fission products depend upon the fissioning isotope, LFPs should be modeled separately for each important fissionable isotope in the problem. The modeling of LFPs can also depend upon the reprocessing plant performance. For example, rare earth elements are not completely removed in pyroprocessing, but ~5% of them are carried into the recycled fuel. In this situation, a separate lumped fission product for rare earth elements can be modeled for each important fissionable isotope. The multigroup cross sections of LFP for a fissionable isotope should be determined by appropriate spectrum weighting of the multigroup cross sections of individual fission products. The yield fraction of a LFP in REBUS is flexible and allows at least two different setups. If the sum over all fission products merges the cross section data with the yield fraction of the fission product, then the REBUS yield fraction should be one. On the other hand, if the weighted average of the cross section data of individual fission products is used, the LFP yield fraction should be the sum of the yield fractions of individual fission products (a number between 1 and 2). It is important to define the mass of the lumped fission product using card type 24 of A.BURN to ensure the mass balance of the system is meaningful.

As mentioned in Section 2.1.1, the zones and sub-zones are defined by their constituent atomic densities using the types 13 and 14 cards of the neutronics input dataset A.NIP3. In a non-equilibrium problem with a given initial reactor configuration, the actual atomic densities of active and inactive isotopes are used in defining compositions. For an enrichment search problem, however, the atomic densities of active isotopes are not known at the beginning of problem. In an enrichment search problem, the atomic densities of active isotopes should be set to 1.0 when defining compositions.

The active isotopes used to specify the isotopic chain must be represented in the ISOTXS microscopic cross section dataset provided by the user. Since it is often desirable to use different cross sections for the same isotope in different regions of the reactor due to varying spectra, one often uses a number of different names for the same physical isotope in a cross section set (e.g. U235I, U235O, etc.). The REBUS transmutation chain should be defined with global isotope labels (U235, PU239, LFP, etc.) and the list of region dependent isotope labels in ISOTXS should be mapped to these isotope labels using card type 10 of A.BURN. For example, one can use U235 as the active isotope label for ^{235}U and can then have ISOTXS labels U235I, U235O, and U235B referring to ^{235}U in the inner and outer core regions and in the radial blanket of a reactor.

Specification of Fuel Management Paths

Each unique fuel management path or fuel shuffling scheme is defined on card type 11 or 35 of A.BURN and given a unique “path label.” As mentioned in Section 2.1.1, card type 11 is used to define a repetitive fuel management scheme while card type 35 is used to define general non-repetitive fuel management schemes. On card type 11, the fuel bundle to be moved is identified

by the sub-zone (i.e., secondary composition) label and the location of this fuel in the reactor is given by the primary composition (i.e., zone in the CCCC terminology) label, or alternatively by the region or fuel management group label.

If the type 35 cards are being used instead, the fuel bundle can be identified by the primary or secondary composition label, and the location by the region, fuel management group or primary composition label, respectively. It is noted that a general non-repetitive fuel management scheme, which includes temporary out-of-core storage, loading of fresh fuel, and subsequent retrieval and reloading of the fuel, can be specified using card types 35, 36, and 37. As mentioned above, card type 36 is used to modify the default shutdown time and length of each burn cycle specified on card type 03, and thus it can be used with the repetitive fuel management strategy specified on card type 11.

A fuel management group label is the union of regions to be moved together. The fuel management group label is defined with card type 45 of A.BURN. Using the fuel management group label, the number of cards (type 11 or 35) can be reduced significantly. For example, in a 3D problem, all axial regions in the same fuel assembly can be moved together using a fuel management group.

As discussed in Section 2.1.2, there are two different types of repetitive fuel management paths: those which move fuel to different regions or to out-of-core storage, and those which do not. In a scattered reloading scheme (typical for equilibrium problems), there is no movement of fuel from one region to another. If a particular primary composition is specified for each of N_s stages in a path, then $1/N_s$ of the fuel will be removed at each fuel management step in each region to which the zone was assigned (via the type 15 cards of A.NIP3). For example, consider the 3-batch equilibrium cycle problem shown in Fig. 2.3. In this case, denoting the sub-zones with a suffix "_S," the fuel management path for the zone "A" can be specified in the fixed format of A.BURN as:

```
11      PATH1      0     1 A_S    A          2 A_S    A
11      PATH1      0     3 A_S    A          4 A_DS
```

This fuel management path implies that the sub-zone "A_S" is loaded into the regions where the zone "A" is assigned, stays in the same regions for three cycles, and then is discharged with the label "A_DS," which will be used later in defining reprocessing plants. As shown in Fig. 2.3, the zone "A" is assigned to the three regions R201, R301, and R302. Thus, REBUS defines three unique zones "R201," "R301," and "R302" by duplicating zone "A" as discussed in Section 2.1.1. At the beginning of equilibrium cycle, the regions R201, R301, and R302 are loaded with the stage 1 to 3 fuels of zones R201, R301, and R302, respectively, with equal volume fractions of $\frac{1}{3}$. At the end of cycle, the stage 4 (i.e., thrice-burned) fuels are discharged, and the stage 1 fuels of zones R201, R301, and R302 are loaded into the regions R201, R301, and R302, respectively.

In a repetitive fuel management scheme with fuel reloading and shuffling, fuels are shuffled at the end of each cycle by carrying out the move sequence specified on card type 11 repeatedly. For example, consider the 3-batch equilibrium cycle problem in Fig. 2.4. In this case, the fuel management path for the zone "A" can be specified in the fixed format of A.BURN as:

```
11      PATH1      0     1 A_S    R301       2 A_S    R201
11      PATH1      0     3 A_S    R302       4 A_DS
```

At the beginning of cycle, the regions R301, R201, and R302 contain the sub-zones "A_S" of stages 1, 2, and 3, respectively. At the end of each cycle, the fuels in R301 and R201 become the sub-zones "A_S" of stages 2 and 3, respectively, and the fuel in R302 becomes the discharge fuel "A_DS." The discharge fuel "A_DS" in R302 is discharged from the reactor, and then the stage 3 fuel in R201 is moved to R302. Subsequently, the stage 2 fuel in R301 is moved to R201, and a fresh fuel is charged into R301. Therefore, at the beginning of the next cycle, the regions R301, R201, and R302 contain the sub-zones "A_S" of stages 1, 2, and 3, respectively, as in the previous cycle.

Burnup Dependent Cross Sections

REBUS permits time-dependent microscopic capture and fission cross sections during the depletion calculations. In this way, one can take approximate account of spectral shifts, self-shielding effects, and other factors which require adjustment of the microscopic group constants as a function of burnup. The code assumes that the burnup-dependent microscopic cross sections of various user specified isotopes can be correlated with the atomic density of a specific isotope referred to as the reference base isotope. It is further assumed that this correlation can be expressed mathematically as a power series expansion in terms of the atomic density of this reference base isotope.

Specifically, the relative cross section (i.e., a fractional value relative to a specific base cross section) of a particular energy group and isotope is represented as a polynomial of the atomic density of the corresponding reference base isotope (typically ^{235}U). All burnup dependent isotopes in a given region of the reactor being calculated must refer to the same reference base isotope. However, different reference base isotopes may be used in different regions. Thus, for example, the burnup dependent isotopes in a core might be correlated with the burnout of ^{235}U whereas in a depleted uranium blanket, the correlation could be with the buildup of ^{239}Pu. When generating macroscopic cross sections for flux calculations and the transmutation matrices for depletion, the microscopic capture and fission cross sections are determined by multiplying the base cross sections with the relative cross sections. The relative cross sections are determined by evaluating the polynomial using the reference isotope atom density in each region.

The POLYFI module of REBUS is invoked to perform a least squares fitting to calculate the expansion coefficients. The lowest possible order fit is determined consistent with user criteria for the maximum allowable relative residual and the maximum order permitted for the fit.

Separate expansions are performed for capture and fission and for each of the specified energy groups.

The data required to specify the fitting parameters is supplied by the user in the BCD dataset A.BURN on the card types 26 and 39 through 41. The inclusion of card type 26 invokes the burnup dependent cross section treatment. Card type 26 is used to specify the ISOTXS labels of the reference base isotopes and of the corresponding burnup dependent isotopes. Both isotopes should appear in the card type 13 or 14 input data of A.NIP3. The user specifies the groups which are to be treated as burnup dependent for the various burnup dependent isotopes using card type 39. Card type 40 is used to select the fitting, (n,γ), (n,f) or both, and the criteria for the maximum relative residual and order of the polynomial. Finally, card type 41 is used to select the ISOTXS labels of the isotopes to be used in the polynomial fit along with the corresponding atomic densities for the reference base isotope and the weights to be used during the fitting.

The microscopic cross sections for the burnup dependent isotopes along with those which provide the correlation of cross section vs. atomic density of the reference base isotope must be supplied in the ISOTXS file.

2.2. Ex-Reactor Cycle Models

The ex-core model specifies how the reactor is to be loaded initially from the external cycle materials and subsequently refueled over the course of the burn cycles with these same materials. It consists of the following successive steps: charge, discharge and cooling, reprocessing, and re-fabrication. Fig. 2.7 shows a schematic description of the external cycle model along with the relevant data card types of A.BURN used to describe each particular phase of the external cycle. Note that the post-reprocessing sale is identified with the material selection and fabrication portion of the external cycle discussed below in Section 2.2.4. For accounting purposes, this sale is assumed to take place immediately following reprocessing.

2.2.1. Reactor Charge Specifications

Card type 12 of A.BURN is used to describe the fabricated fuel that is to be loaded into the reactor at the fuel management time. For each fuel management path described on the card type 11 or 35, one specifies the fabrication time and the pre-loading storage time on card type 12. The user also specifies the initial “enrichment” (some of which may be 0.0) of the fuel as well as an “enrichment modification factor” to be used in adjusting the initial enrichment in those problems in which there is a charge-enrichment search. Radioactive decay processes are accounted for in each material over the specified fabrication and preloading storage times according to the isotopic decay schemes specified on card type 09 and 25.

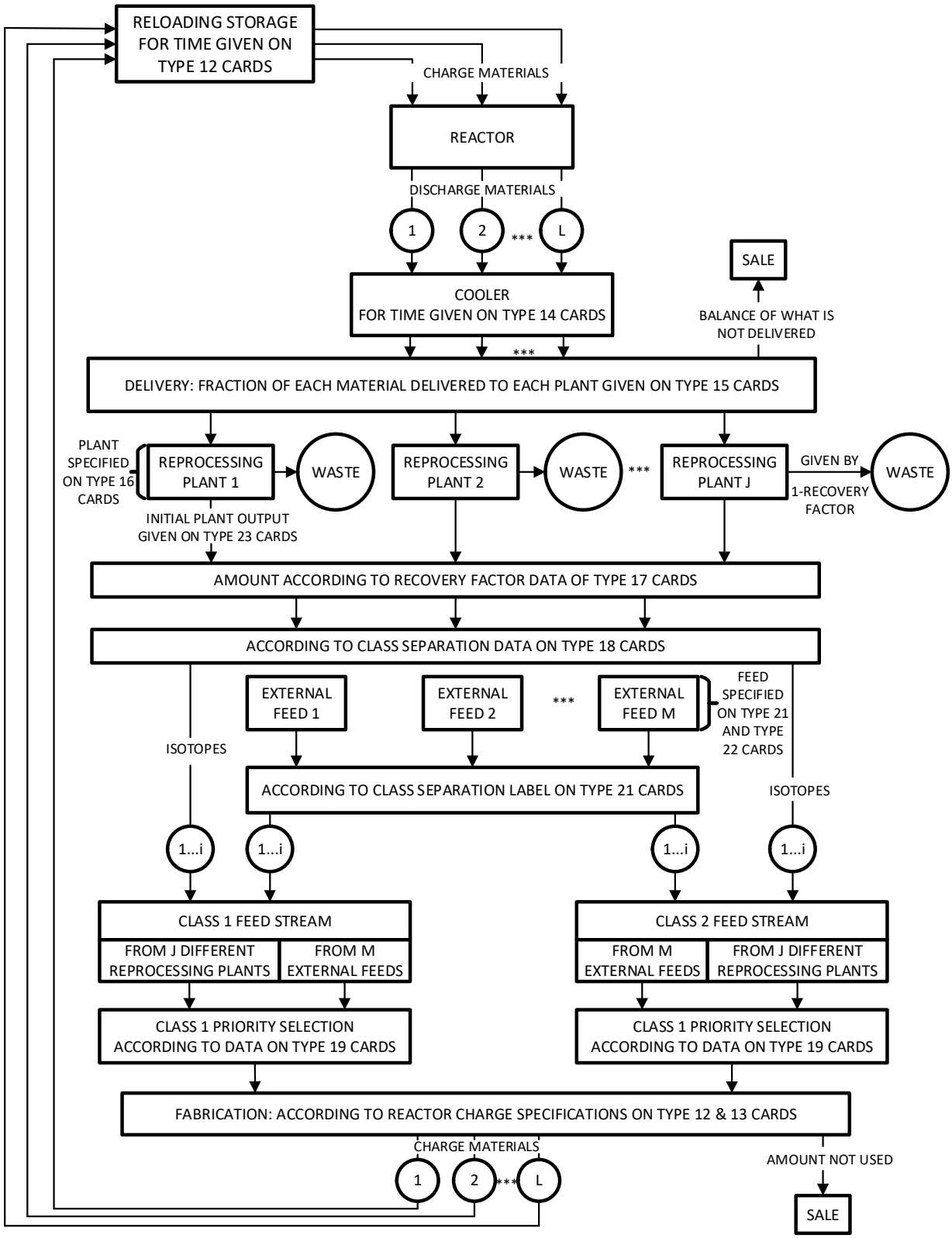


Fig. 2.7. Schematic Diagram of External Cycle Model

In REBUS, the enrichment of fuel translates to a volume fraction representing the fraction of the total fresh charge volume that is to be made up from the high reactivity feed fuel stream, conventionally termed CLASS 1 feed. In other words, it is defined as the ratio of the CLASS 1 fuel volume to the total (CLASS 1+CLASS 2) volume of the charge fuel. The specification of CLASS 1 and CLASS 2 fuel is arbitrary and is described below in Section 2.2.4. Conceptually, the reactor multiplication factor should be sensitive to variations in the fuel enrichment but this is not itself a requirement. The fraction of the total volume of fuel required for each fresh charge that is not made up from CLASS 1 feed will be made up from the low-reactivity feed stream CLASS 2. The required volume of fuel to be fabricated is determined by the "active" volume of each charge material, i.e., the volume occupied by the active isotopes in each material.

Card type 13 is used to define the fuel fabrication label and identify a particular set of atomic densities for the active isotopes. These are as-fabricated fuel densities and may correspond to a selected fuel composition at some percentage of its theoretical density (TD). The specific value of the heavy metal density will depend on the particular chemical and physical composition of the fuel charges being fabricated (e.g., oxide, carbide, or metal alloy) fuel at some percentage of TD and heavy metal weight fraction. A fuel fabrication label is defined using the active isotope labels on the type 09 cards and their pure isotope fabrication densities (in the unit of atoms per cm-barn). The fabrication density of a pure isotope translates to the atoms per unit volume that is required in fabrication to yield a desired heavy metal density, assuming the composition is composed only of the given isotope. The fabrication density of a pure isotope for active isotope i can be calculated using

$$N_i^{pure} = \frac{\rho_{HM} N_A}{A_i}, \tag{2.1}$$

where ρ_{HM} denotes the heavy metal density of the fuel, N_A is Avogadro's number, and A_i is the atomic mass of isotope i. It is noted that the atomic density of isotope i (N_i) can be determined by multiplying the isotope weight fraction in heavy metal (ω_i) to this fabrication density of pure isotope i. The isotopic content of an external feeds is done with card type 22 of A.BURN, but it is calculated for recycled fuels based upon the setup of the external cycle.

As an example, consider the oxide fuel PuO_2 at 95% TD. Using a TD of 11.4 g/cm^3 and a computed 88 weight percent heavy metal, the heavy metal density is 9.5304 (=11.4×0.95×0.88) g/cm^3. Given this, the fabrication density of a pure isotope can be determined for each active Pu isotope by dividing this heavy metal density by the atomic weight of each isotope. Using the default value of 0.6022054×10^{24} for Avogadro's number, which can be modified with card type 28, and the atomic masses given in Table 2.8, the required isotopic fabrication densities can be determined as in Table 2.8.

Table 2.8. Example Isotopic Fabrication Densities of PuO_2 Fuel

Isotope	Atomic Mass	Fabrication Density of Pure Isotope (atoms/barn·cm)
^{238}Pu	238.0495	2.41095E-02
^{239}Pu	239.0522	2.40084E-02
^{240}Pu	240.0540	2.39082E-02
^{241}Pu	241.0563	2.38088E-02
^{242}Pu	242.0587	2.37102E-02

As another example, consider U-20Pu-10Zr ternary metal alloy fuel which infers 20% (weight) of Pu, 10% Zr, and 70% U. Assuming a fabrication density of 15.73 g/cm^3, the density of the heavy metal component of U-20Pu-10Zr would be 14.16 (=15.73×0.90) g/cm^3. Thus, with a value of 0.602214×10^{24} for Avogadro's number and the atomic masses given in Table 2.9, the isotopic fabrication densities shown are obtained. Note that Am and Cm isotopic densities are included for the use in re-fabrication of recycled fuel with these isotopes which are also based upon the heavy metal fabrication density of 14.16 g/cm^3.

Table 2.9. Example Isotopic Fabrication Densities of U-20Pu-10Zr Metal Alloy Fuel

Isotope	Atomic Mass	Fabrication Density of Pure Isotope (atoms/barn·cm)
^{234}U	234.0409	3.64276E-02
^{235}U	235.0439	3.62721E-02
^{236}U	236.0456	3.61182E-02
^{238}U	238.0508	3.58140E-02
^{237}Np	237.0482	3.59654E-02
^{236}Pu	236.0458	3.61182E-02
^{238}Pu	238.0495	3.58141E-02
^{239}Pu	239.0522	3.56639E-02
^{240}Pu	240.0542	3.55151E-02
^{241}Pu	241.0487	3.53685E-02
^{242}Pu	242.0584	3.52210E-02
^{241}Am	241.0568	3.53673E-02
^{242}Am	242.0594	3.52209E-02
^{243}Am	243.0614	3.50757E-02
^{242}Cm	242.0584	3.52210E-02
^{243}Cm	243.0610	3.50757E-02
^{244}Cm	244.0626	3.49318E-02
^{245}Cm	245.0652	3.47889E-02
^{246}Cm	246.0668	3.46473E-02
^{247}Cm	247.0705	3.45065E-02
^{248}Cm	248.0720	3.43672E-02

Figure 2.8 shows an example use of card type 12 and 13 of A.BURN. To facilitate the discussion, the type 11 cards are also included for an equilibrium cycle problem with a scatter loading. The reactor is loaded with three different material types of U-Pu-10Zr metal alloy fuel. The three primary compositions are named "ICPC," "MCPC," and "OCPC" with the corresponding secondary composition labels "ICSC," "MCSC," and "OCMC." A 3-batch fuel management scheme is used for the inner and middle core compositions "ICPC" and "MCPC," while a 4-batch fuel management scheme is used for the outer core composition "OCPC." The discharge fuels of "ICSC," "MCSC," and "OCSC" are labeled as "ICDS," "MCDS," and "OCDS," respectively.

```
11    CPL1       0    1 ICSC  ICPC      2 ICSC  ICPC
11    CPL1       0    3 ICSC  ICPC      4 ICDS
11    CPL2       0    1 MCSC  MCPC      2 MCSC  MCPC
11    CPL2       0    3 MCSC  MCPC      4 MCDS
11    CPL3       0    1 OCSC  OCPC      2 OCSC  OCPC
11    CPL3       0    3 OCSC  OCPC      4 OCSC  OCPC
11    CPL3       0    5 OCDS
12    CPL1        ICLOAD      0.0           0.0        1.00         1.0
12    CPL2        MCLOAD      0.0           0.0        1.25         1.0
12    CPL3        OCLOAD      0.0           0.0        1.60         1.0
13    ICLOAD      U-234  3.64276E-2 U-235 3.62721E-2
13    ICLOAD      U-236  3.61182E-2 U-238 3.58140E-2
13    ICLOAD      NP237  3.59654E-2 PU236 3.61181E-2
13    ICLOAD      PU238  3.58141E-2 PU239 3.56639E-2
13    ICLOAD      PU240  3.55151E-2 PU241 3.53674E-2
13    ICLOAD      PU242  3.52210E-2 AM241 3.53673E-2
13    ICLOAD      AM242  3.52209E-2 AM243 3.50757E-2
13    ICLOAD      CM242  3.52209E-2 CM243 3.50757E-2
13    ICLOAD      CM244  3.49318E-2 CM245 3.47888E-2
13    ICLOAD      CM246  3.46472E-2 LEC44 1.18017E-1
13    ICLOAD      LFU35  5.07987E-2 LFU38 4.95931E-2
13    ICLOAD      LFN37  4.86230E-2 LFP38 4.84819E-2
13    ICLOAD      LFP39  4.72854E-2 LFP40 4.75703E-2
13    ICLOAD      LFP41  4.70773E-2 LFP42 4.80340E-2
13    ICLOAD      LFA41  4.81479E-2 LFA43 4.81887E-2
13    ICLOAD      LFC44  5.04859E-2 LEU35 1.30141E-1
13    ICLOAD      LEU38  1.33274E-1 LEN37 1.42639E-1
13    ICLOAD      LEP38  1.39878E-1 LEP39 1.51296E-1
13    ICLOAD      LEP40  1.45388E-1 LEP41 1.38604E-1
13    ICLOAD      LEP42  1.37553E-1 LEA41 1.38402E-1
13    ICLOAD      LEA43  1.35628E-1
13    MCLOAD      U-234  3.64276E-2 U-235 3.62721E-2
...
13    MCLOAD      LEA43  1.35628E-1
13    OCLOAD      U-234  3.64276E-2 U-235 3.62721E-2
...
13    OCLOAD      LEA43  1.35628E-1
```

Fig. 2.8. Example Charge Specification and Fuel Fabrication Data

Card type 12 are used to specify that the fuel management paths "CPL1," "CPL2," and "CPL3" will be charged with the fabricated fuels "ICLOAD," "MCLOAD," and "OCLOAD," respectively. For all the three fabricated fuels, zero re-fabrication and preloading storage times are assumed. Note that these times can be included in the reprocessing time. The initial enrichments 1.00, 1.25, and 1.60 for "ICLOAD," "MCLOAD," and "OCLOAD" indicate that an enrichment split strategy is adopted in this core to flatten the power distribution. During the procedure to search for the charged fuel enrichment, the enrichment of a batch of fresh fuel of type l is adjusted according to the following formula:

$$e_l = e_{l0}[1+(x-1.0)\delta_l], \tag{2.2}$$

where e_{l0} and δ_l are the initial enrichment and enrichment modification factor of the material type l, respectively, specified on card type 12. The variable x is the charged fuel enrichment search parameter to be determined, and its initial and second guesses are specified by the user on the type 04 card. The enrichment parameter is determined iteratively to achieve a targeted multiplication factor at a specified time point. Starting from two user-specified enrichment parameter guesses, a new estimate of the enrichment parameter is successively calculated by interpolating the latest two or three enrichment parameters and the corresponding multiplication factors.

Card type 13 is used to define the isotopic fabrication density of a pure isotope discussed earlier and defined in Eq. (2.1). The isotope labels in card type 13 must be an active isotope label specified on card type 09 and the mapping in card type 10 applies on a region-wise basis to ensure region dependent cross section data. The provided example above shows the isotopic fabrication densities for the fabricated fuel "ICLOAD" and excerpts of the input for "MCLOAD" and "OCLOAD" are given noting that they have the same fabrication densities as "ICLOAD." In this problem, "LExxx" denotes the rare earth lumped fission product of fissioning isotope "xxx," and "LFxxx" denotes the lumped isotope of the remaining fission products. As an example, LEU35 is the rare earth lumped fission product and LFU35 is the non-rare earth lumped fission product for U-235.

2.2.2. Reactor Discharge Specifications

The normal procedure following the discharge of a fuel bundle from the reactor is assumed to be storage in a cooling pool followed by transfer to one or more reprocessing plants. As mentioned earlier in Section 2.1.2, if a fuel management path has N_s stages, a discharge label for this path is defined as the N_s+1 stage on card type 09 of A.BURN. Each discharge label has a cooling time associated with it, which is specified with card type 14 of A.BURN. This cooling time may logically also include the time required for delivery to the reprocessing plants specified on card type 15. For each discharge label, any number of reprocessing plants may be specified as destinations. One also specifies here the fraction of the discharged material to be delivered to each reprocessing plant. All of the reactor discharge material not delivered to a reprocessing plant will be considered to be sold.

As an example, consider the above sample problem in Section 2.2.1 loaded with three different material types whose discharge labels are specified on the type 09 cards as "ICDS," "MCDS," and "OCDS." If all three types of discharge fuels are cooled for one year and sent to a single reprocessing plant "REPC," then card type 14 and 15 are written as:

```
14    ICDS       365.25 MCDS       365.25 OCDS       365.25
15    ICDS        REPC   1.0
15    MCDS        REPC   1.0
15    OCDS        REPC   1.0
```

Excess material can be sold both directly after cooling and following reprocessing. The discharged fuel material of each type may be cooled for a different period, then divided before being dispatched to different reprocessing plants. Discharged fuel of different material types may be mixed as a single input to a reprocessing plant. Radioactive decay processes are accounted for in each material over the specified cooling and/or fuel transfer times according to the isotopic decay schemes specified on the type 09 and 25 cards.

Note that when an isotope has been discharged from the reactor and fed into a reprocessing plant, the specific identification of that isotope with the region-wise self-shielded microscopic cross section is lost. Hence, all atoms of that isotope from all of the various materials are counted together.

2.2.3. Reprocessing

As mentioned in Section 2.2.2, the cooled fuel may be divided and/or combined for input to one or more reprocessing plants. Each of these plants has an associated reprocessing time which is specified with card type 16. Each reprocessing plant is assigned a set of "recovery fractions" for each active isotope being processed using card type 17. This is the primary card input that allows simulation of the reprocessing plant losses such as removal of fission products. Using card type 18, each reprocessing plant is assigned a "process separation fraction" which gives the fraction of each isotope recovered for the CLASS 1 and 2 feed streams. Note that each reprocessing plant is assumed to operate on all of the discharged fuel at once. This approximation was made in order to simplify the calculation of fuel availability for re-fabrication. The real continuous process can be simulated by introducing multiple reprocessing plants in place of one reprocessing plant and assigning a different reprocessing time to each part with card types 15 and 16.

Consistent with the preceding A.BURN examples, Fig. 2.9 shows an example of a reprocessing plant specification. The type 16 card specifies a reprocessing plant "REPC" that has a recovery factor specification of "RFC," a class separation fraction of "DSNF," and a reprocessing time of 182.5 days. Card type 17 defines the recovery factor specification label "RFC" defining a recovery factor of 1.0 for all uranium and plutonium isotopes (U-235, PU239, etc.), and a recovery factor of 0.05 for the rare earth fission product lumps (LEU25, LEU28, etc.). Thus, it is assumed that uranium and plutonium isotopes are completely recovered from

the discharged fuel and can be recycled back into the reactor with some contaminant of rare earth fission products. The minor actinides (AM241, CM242, etc.) and lumped fission products (LFU25, LFP39, etc.) are not present and thus by default assigned a value of 0.0. In this manner, they are not recycled back into the reactor and REBUS simply reports the isotopic mass not recovered from the reprocessing plant. Card type 18 is used to define "DSNF" which specifies that all of the plutonium isotopes and U-235 are defined as CLASS 1 fuel while U-234, U-236, and U-238 are defined as CLASS 2 fuel. This implies perfect enrichment is achieved in the reprocessing plant such that the U-235 is separated from the other uranium isotopes, and thus demonstrates the flexibility in the reprocessing input itself.

```
16    REPC  RFC   DSNF        182.5
17    RFC         U-234 1.00        U-235 1.00        U-236 1.00
17    RFC         U-238 1.00        PU236 1.00        PU238 1.00
17    RFC         PU239 1.00        PU240 1.00        PU241 1.00
17    RFC         PU242 1.00        LEU25 0.05        LEU28 0.05
17    RFC         LEN37 0.05        LEP38 0.05        LEP39 0.05
17    RFC         LEP40 0.05        LEP41 0.05        LEP42 0.05
17    RFC         LEA41 0.05        LEA43 0.05        LEC44 0.05
18    DSNF        U-234 0.0         U-235  1.0        U-236  0.0
18    DSNF        U-238 0.0         PU236  1.0        PU238  1.0
18    DSNF        PU239 1.0         PU240  1.0        PU241  1.0
18    DSNF        PU242 1.0
```

Fig. 2.9. Example Reprocessing Plant Specification

Optionally, one may also specify an initial batch volume for each reprocessing plant with card type 16 and the composition of that batch with card type 23. As noted previously, by specifying an external cycle for a particular problem, one is in fact specifying how the initially empty reactor is to be loaded in order to start the burn cycles. Normally this initial fabrication to load the empty reactor is made from fuel supplied exclusively from external feeds. There is no material available from the reprocessing plants due to the simple fact that no material has been discharged from the reactor as yet and sent to these plants. However, by the use of the type 23 cards, this initial fabrication may also include material from the reprocessing plants.

2.2.4. Re-fabrication and External Feed

The re-fabrication phase is difficult to arrange into a fully determined, yet flexible scheme that is easy for the user to specify in terms of input data requirements. When setting up a problem, the initial enrichment of each charge material is unknown and thus the specific high- and low-reactivity fuel requirements are unknown. Since the model includes reprocessing plants, the discharged fuel, and therefore part of the re-fabrication fuel inventory is undefined until the reactor performance itself is known. The method adopted in REBUS is a priority ordering scheme which is relatively easy to specify and is not unduly restrictive in scope.

At some minimum time before the refueling date, a choice of fuel for re-fabrication is made. Fuel is available in the form of high-reactivity (CLASS 1) and low-reactivity (CLASS 2) batches, each with fixed isotopic ratios. There may be a number of these, some of which represent reprocessed fuel and some of which come from external feeds. In each particular application there are preferences for using one type of fuel over the others, but one may be forced to use some second-choice material because of the limited amount of fuel available. While there may be a preferential use of the available feed fuel, there may again be a limited amount of feed material available. There must, of course, be enough CLASS 1 and 2 fuel available to complete the makeup of all fabricated materials charged in each time step.

There is also a choice when distributing the available fuel among the charged assemblies that must be fabricated. There may be a preference to use one type of feed for a particular fuel assembly, and a preference to use any surplus of that feed in the fabrication of another fuel assembly. There may also be a commitment to sell some of the reprocessed fuel. The following is a description of the priority scheme which has been devised to express these options when fabricating fresh fuel. While the scheme cannot treat all conceivable possibilities, it is simple to specify and to calculate and is applied in the same manner for CLASS 1 and CLASS 2 feed streams though the specifications may be different for each.

The first part of the scheme is an absolute order of preference, given for each charge material, of the choice of sources to be used in fabricating that material. A "priority level" of 1 (the highest priority level) for use of fuel from a reprocessing plant or external feed implies that all atoms of that fuel will be used for fabrication of the charge material if they are needed and available. This is modified by a "distribution fraction" as discussed below. Any surplus material will be made available for use in lower priority fabrication requests. If one material shows priority 1 for more than one type of fuel, those fuels will be used in fabrication in proportion to the number of atoms available from each storage or feed.

If two or more materials have priority 1 for the same fuel source, the total available atoms will be distributed in proportion to a "distribution fraction," which is inputted along with each priority number. A default value of 1.0 is assumed. The given distribution fractions are renormalized among the materials to which the available atoms of a fuel source are to be distributed at the same priority level. If after such a distribution there are still atoms of fuel available (if one or more of the fabricated materials is completed), the surplus is distributed at priority level 1 in proportion to the original distribution fractions of those materials which are not yet complete. When all operations at priority level 1 are completed, the calculation proceeds to priority level 2, and so on until fabrication is completed. Note that fuel recovered from blankets can also be treated by the priority system and allows some of the material to be sold. The priority levels and distribution fractions of each source (reprocessing plant or external feed) to be used in the fabrication of a material are specified for CLASS 1 fuel with card type 19. The same type of priority system is specified for the CLASS 2 fuel supply with card type 20.

The external feed supplies provide an independent source of fuel for fabrication. The name of each external feed and its associated volume are defined using card type 21. Card type 18 is used to describe how the feed supply is split between CLASS 1 and CLASS 2. The volume of at least one external feed should be large enough to ensure that there will always be enough CLASS 1 and CLASS 2 fuel to fabricate all required materials. The specific isotopic composition of each feed is defined using card type 22. These atomic densities, when combined with the total feed volumes specified on card type 21, determine the total number of atoms of each isotope available from each external feed.

Figure 2.10 shows an example external feed specification. Card type 21 defines two external feeds "EFA" and "EDU" with class separation labels "SEPR1" and "SDU," respectively. A large default volume of 1.0×10^{30} cm^3 is assumed for both external feeds. The isotopic compositions of the external feeds "EFA" and "EDU" are defined using card type 22. The external feed "EFA" is a uranium-plutonium fuel, and the external feed "EDU" is depleted uranium. The CLASS separation factors for both external feeds "EFA" and "EDU" are defined with card type 18. Similar to the processing plant input example shown earlier, all of the plutonium isotopes and U-235 are defined as CLASS 1 and U-234, U-236, and U-238 are defined as CLASS 2 fuel. The lumped rare earth fission products of "EFA" and all of the isotopes of the depleted uranium feed "EDU" are defined as CLASS 2 fuel.

```
18    SEPR1       PU242 1.00        PU236 1.00        PU238 1.00
18    SEPR1       PU239 1.00        PU240 1.00        PU241 1.00
18    SEPR1       U-238 0.00        U-235 1.00        U-236 0.00
18    SEPR1       U-234 0.00
18    SEPR1       LEU35 0.00        LEU38 0.00
18    SEPR1       LEN37 0.00        LEP39 0.00        LEP40 0.00
18    SEPR1       LEP41 0.00        LEP42 0.00        LEA41 0.00
18    SEPR1       LEA43 0.00        LEC44 0.00
21    EFA   SEPR1       1.0E30
22    EFA         U-234 1.72181E-06 U-235 1.78085E-05
22    EFA         U-236 1.60326E-04 U-238 1.41010E-02
22    EFA         PU236 3.78889E-10 PU238 1.35314E-05
22    EFA         PU239 1.73508E-03 PU240 5.53292E-04
22    EFA         PU241 6.13023E-05 PU242 1.83958E-05
22    EFA         LEU35 2.99740E-06 LEU38 6.98488E-06 LEN37 6.83254E-08
22    EFA         LEP38 1.44852E-07 LEP39 2.91639E-05 LEP40 1.63746E-06
22    EFA         LEP41 9.34144E-07 LEP42 2.55562E-08 LEA41 1.28406E-08
22    EFA         LEA43 9.32034E-10 LEC44 5.65424E-10

18    SDU         U-235 0.0         U-238 0.0
21    EDU   SDU         1.0E30
22    EDU         U-238 0.993 U-235 0.007
```

Fig. 2.10. Example Reprocessing Plant Specification

Figure 2.11 shows an example fabrication specification of CLASS 1 and CLASS 2 fuels. Card types 19 and 20 specify the order of preference of the choice of CLASS 1 and CLASS 2 fuel sources, respectively, for the fabrication of the fresh fuel for the three fuel management

paths “CPL1,” “CPL2,” and “CPL3.” For each path, there is a card type 19 to specify priority 1 for the reprocessing plant “REPC” and one to specify priority 2 for the external feed “EFA” both with the default distribution fraction of 1.0. Therefore, the available CLASS 1 stream from “REPC” will be distributed with equal priorities to the three paths. If the distributed CLASS 1 stream from “REPC” is insufficient to complete the fabrication of all paths, the remainder will be taken from the CLASS 1 fuel of the external feed “EFA.” Similarly, each path has a card type 20 to select the CLASS 2 stream from “REPC” followed by one to select CLASS 2 from the external feed “EDU.”

```
19    CPL1        REPC        1
19    CPL1        EFA         2
19    CPL2        REPC        1
19    CPL2        EFA         2
19    CPL3        REPC        1
19    CPL3        EFA         2
20    CPL1        REPC        1
20    CPL1        EDU         2
20    CPL2        REPC        1
20    CPL2        EDU         2
20    CPL3        REPC        1
20    CPL3        EDU         2
```

Fig. 2.11. Example Fabrication Specification of CLASS 1 and CLASS 2 Fuels

From Fig. 2.10 earlier, card type 18 selected the U-235 and plutonium isotopes as CLASS 1 fuel while the other uranium isotopes and rare earth elements were classified as CLASS 2 fuel. Therefore, the enrichment is defined as the volume ratio of U-235 and plutonium isotopes to all heavy metal isotopes and rare earth lumped products.

Another example to illustrate the priority system for selection of fuel charge batches is given in Table 2.10 which assumes a plutonium-uranium fueled fast breeder reactor. Given two different enrichment regions in the core (Core Charge 1 and Core Charge 2) and a single blanket composition, the example assumes that the core discharge fuel is sent to plant “A” while the blanket discharge fuel is sent to plant “B.” Priority 1 for CLASS 1 (U-235 and Pu) can be identified as the reprocessing plant “B” column. As can be seen, the content is split between “Charge 1” and “Charge 2” with 25% of the volume being sold. A 2 to 1 volume ratio is assigned between “Charge 1” and “Charge 2” for the other 75% of the reprocessed CLASS 1 fuel from reprocessing plant B. If there is insufficient material from reprocessing plant “B” to complete the fabrication, the next priority is identified as the reprocessing plant “A” column. If there is excessive CLASS 1 material from both reprocessing plants, the excess will be sold as indicated with the priority 3 setting for reprocessing plant “A.”

All the CLASS 2 fuel recovered from plants “A” and “B” is prioritized to be used first for blanket charge fabrication, and then for the core charges. Any external feed required to complete the fabrication will be obtained first from a limited volume feed (external feed “C”) and then

from a second feed of unlimited volume (external feed "D"). Note that REBUS will automatically normalize the distribution fractions provided by the user. Thus for priority 3 of CLASS 2, the stated 1.0 values shown will each be modified to 0.333 by REBUS during execution.

Table 2.10 Example of Priority System for Selection of Fuel Charge Batches

Path Label or Sale Label	Priority Level/Distribution Fraction							
	CLASS 1 Fuel				CLASS 2 Fuel			
	Reprocessing Plant		External Feed		Reprocessing Plant		External Feed	
	A	B	C	D	A	B	C	D
Core Charge 1	2/1.0	1/0.5	3/1.0	4/1.0	2/1.0	2/1.0	3/1.0	4/1.0
Core Charge 2	2/1.0	1/.25	3/1.0	4/1.0	2/1.0	2/1.0	3/1.0	4/1.0
Blanket					1/1.0	1/1.0	3/1.0	4/1.0
Sale	3/1.0	1/.25						

2.3. Non-equilibrium Cycle Problems

The charge enrichment search capability applies to non-equilibrium cycle problems as well as equilibrium cycle problems. For a problem with the charge enrichment search option, however, only fresh fuels can be introduced into the reactor at the beginning of the problem. In order to determine the charge enrichment of fresh assemblies for a non-equilibrium cycle problem with partial reloading, where only part of the discharged assemblies are replaced with fresh assemblies, the REBUS model must include the first cycle loaded with all fresh fuel and all intermediate cycles up to the last cycle of interest. An enrichment search capability for partial reloading has been developed to permit its application to a wide range of fuel management strategies [20]. The charge enrichment of fresh fuel can be determined without performing the previous burn cycle analyses for an arbitrary core composed of fresh and burned fuel assemblies. However, this capability has not been implemented to the production version of REBUS.

A non-equilibrium recycle capability is also available, which permits modifying the external feed sources based on the fuel that was discharged from specified regions in the burn cycle preceding the last burn step. In particular, beginning at burn cycle number 3, the feed isotopes and quantities used for burn cycle c can be determined by the fuel which was discharged from cycle $c-2$. The user specifies the recovery factors using card type 42 of A.BURN and the regions from which discharged fuel is to be recycled on card type 43. The feed supplies to be altered are specified on card type 44.

The same priority level/distribution fraction concept is applied to the non-equilibrium feed sources as was previously described for equilibrium problems. Typically, the user will provide a supplemental external feed source having a very large volume with a lower priority than that for the normal external feed sources which are to be modified using the recycled fuel. Using this

computational strategy, the user may easily observe whether the system being calculated is self-sustaining using the previously discharged fuel, or whether additional external fuel supplies must be called upon to supplement the fuel makeup.

Figure 2.12 shows an example non-equilibrium recycle specification. This example is based upon 3 fuel management steps with the fuel discharged from cycles 1 and 2 used to modify the number of atoms in the external feed "EFA" used for loading cycles 3 and 4, respectively. The reactor is composed of two core areas, "ICORE" and "OCORE," and one radial blanket area "RBLKT." Here an area denotes a collection of regions. Extra feeds "EFB" and "EFC" are specified on card types 22 and 23, which are depleted and 50% enriched uranium feeds, respectively. For both CLASS 1 and 2 fabrications of "ICORE" and "OCORE" loadings, "EFA" and "EFC" are used at priority levels 1 and 2, respectively. The feed "EFB" is used for the fabrication of radial blanket fuel. The initial volume specified for feed "EFA" is very large such that "EFC" will not be required for the loading of cycles 1 and 2.

```
18    SEPR1       U-235 1.0          U-236 1.0          PU238 1.0
18    SEPR1       PU239 1.0          PU240 1.0          PU241 1.0
18    SEPR1       PU242 1.0          U-238 0.0
18    SEPR2       U-235 0.0          U-238 0.0
21    EFA   SEPR1  1.00000E+30
21    EFB   SEPR2  1.00000E+30
21    EFC   SEPR1  1.00000E+30
22    EFA         U-235 1.0          U-238 1.0
22    EFB         U-235 0.002        U-238 0.998
22    EFC         U-235 1.0          U-238 1.0
42    COREDS      U-235 0.71000176   U-236 0.71000176   U-238  1.000000+30
42    COREDS      PU238 0.71000176   PU239 0.71000176   PU240  0.71000176
42    COREDS      PU241 0.71000176   PU242 0.71000176
42    BLKTDS      U-235 0.0          U-236 0.0          U-238  0.0
42    BLKTDS      PU238 0.71000176   PU239 0.71000176   PU240  0.71000176
42    BLKTDS      PU241 0.71000176   PU242 0.71000176
43    COREDS ICORE OCORE
43    BLKTDS RBLKT
44    EFA    ICORE OCORE RBLKT
```

Fig. 2.12. Example Specification of Non-equilibrium Recycle

Starting with cycle 3, however, the discharge from cycle $c-2$ will be used to determine the composition of feed "EFA" according to the data on card types 42 through 44. Two sets of discharge recovery factors, "COREDS" and "BLKTDS," are specified for each of the active isotopes on the type 42 cards. Note that the number of atoms of U-238 pertinent to the first set will be multiplied by 1.0E+30 corresponding to an unlimited supply for the depleted uranium in the makeup material and that only the plutonium isotopes are recycled for the second set of data. The discharge from the regions contained in the areas "ICORE" and "OCORE" contribute to the first set of recycled atoms ("COREDS") and the regions in the area RBLKT to the second set ("BLKTDS") as indicated on card type 43. Card type 44 indicates that all of the discharged

material will be used to specify the composition of the external feed "EFA." If insufficient material is available in feed "EFA," the feed "EFC" will be used.

2.4. Fuel Cycle Analysis of Accelerator-Driven Systems

As mentioned in the introduction, REBUS was originally designed for the fuel cycle analysis of fast critical reactors but its capabilities were extended in the early 2000s for application to a subcritical ADS [7]. In an ADS, a high-power particle accelerator produces energetic protons that interact with a heavy metal target to produce neutrons. The source neutrons are generated by direct impingement of the accelerator proton beam onto a target material in a process called spallation. The spallation neutrons are subsequently multiplied in the surrounding subcritical blanket. For a REBUS fuel cycle analysis, the spallation neutron sources are specified by the user as an external fixed source distribution [21] using the CCCC fixed source file FIXSRC [19]. The spallation neutron source distribution can be generated using a high-energy physics code such as LAHET [22].

Accelerator-driven systems are mainly considered to transmute TRU into fission products in order to reduce the long-term toxicity contained in the waste consigned to the geological repository [23,24]. In order to increase the TRU consumption rate by reducing the TRU conversion ratio, uranium-free or high TRU fraction fuels are usually proposed. With these fuels, the multiplication factor decreases rather fast with time due to burnup reactivity loss. Thus, to maintain a constant power level, the source intensity is increased over an operating cycle by increasing the accelerator power.

For ADS fuel cycle analysis, a constant power depletion capability and a charged fuel enrichment search capability for fixed source problems were added. The discrete ordinate transport code TWODANT [12] was made callable by REBUS as an additional neutronics solution option in order to model the void regions such as the beam tube in ADS, which cannot be modeled properly with the solvers of DIF3D. Furthermore, the conversion ratio and reactor summary edits that were originally designed for breeder reactors were extended for TRU burners along with various modifications to the output edits.

2.4.1. Fixed Source Problem Calculation

For a fixed source problem, the fuel depletion calculation is performed at a specified power level by scaling the source intensity to compensate for the burnup reactivity loss during an irradiation cycle. At each time node t_n, after solving the neutronics problem for a given independent source distribution, the multiplication factor of the inhomogeneous system is calculated as

$$k_s = \frac{\sum_{g=1}^{G} \int_V dV \nu\Sigma_{fg}(r,t_n)\phi_g(r,t_n)}{\sum_{g=1}^{G} \int_V dV [\nu\Sigma_{fg}(r,t_n)\phi_g(r,t_n) + S_g(r,t_n)]}, \tag{2.3}$$

where r is the position variable, g is the energy group index, $\nu\Sigma_{fg}$ is the macroscopic neutron production cross section, ϕ_g is the scalar group flux, and S_g is the given independent group source. Note that this multiplication factor is not the conventional source multiplication factor defined by the number of fission neutrons per external source neutron. It is defined by the ratio of the number of neutrons produced by fission to the number of neutrons lost by absorption and leakage, and thus it is equivalent to the effective multiplication factor of an eigenvalue problem. The neutron flux and external source intensity are re-normalized to the user-specified power. The charge enrichment search determines the transuranic loading in the fresh fuel such that the specified multiplication factor of the inhomogeneous system can be achieved at the specified time point during the burn cycle.

For the fresh fuel enrichment search problem of a critical reactor, the stage densities are initially guessed equal to the fresh fuel densities corresponding to an assumed enrichment. Although with all fresh fuel the initial multiplication factor is significantly higher than that of the actual burned fuel configuration, the method of successive approximation used in REBUS yields the correct stage densities and multiplication factor. However, this initial guess does not work for a fixed source problem since a fixed source problem has a steady-state solution only when the system is subcritical. Therefore, the initial guess for the stage densities are determined by solving the same problem as an eigenvalue problem without the fixed source. For a given subcritical fuel cycle problem, REBUS executes the eigenvalue problem followed by the fixed source problem without any user intervention. In addition, an external cycle sweep is carried out in the preliminary search level to improve the convergence of the charge enrichment when the external feed has a very different reactivity than the reprocessed fuel.

The fixed source capability is invoked using card type 01 of dataset A.STP027 and card type 03 of dataset A.DIF3D. For convenience, the file description of the BCD dataset A.DIF3D is given in Appendix D.

Because accelerator driven systems sometimes consider the use of uranium-free fuels to maximize the TRU consumption rate, a modification to the typical enrichment methodology needs to be applied. As an example, a pin type fuel form comprised of TRU-Zr alloy particles dispersed in a Zr matrix and clad in ferritic stainless steel was proposed in a previous ADS [25]. With this fuel, the TRU loading required to produce a specified multiplication factor at a specified time point can be determined by defining the charge enrichment as the TRU volume fraction in the fuel. This can be done by including Zr isotopes as active isotopes on the type 09 cards of A.BURN and by classifying them as CLASS 2 fuel on the type 18 cards as in Fig. 2.13. Here “RExx” is a lumped rare earth fission product of fissioning isotope “xx,” and “FPxx” denotes the lumped isotope of the remaining fission products. Note that on the type 09 cards, Zr isotopes are defined with no reactions.

```
09    ZR90      0
09    ZR91      0
09    ZR92      0
09    ZR94      0
09    ZR96      0
18    SEPAR      PU238  1.0       PU239  1.0       PU240  1.0
18    SEPAR      PU241  1.0       PU242  1.0       NP237  1.0
18    SEPAR      AM241  1.0       AM242  1.0       AM243  1.0
18    SEPAR      CM242  1.0       CM243  1.0       CM244  1.0
18    SEPAR      CM245  1.0       CM246  1.0       PU236  1.0
18    SEPAR      U-234  1.0       U-235  1.0       U-236  1.0
18    SEPAR      U-238  1.0
18    SEPAR      FP35   1.0       FP38   1.0       FP39   1.0
18    SEPAR      FP40   1.0       FP41   1.0
18    SEPAR      RE35   1.0       RE38   1.0       RE39   1.0
18    SEPAR      RE40   1.0       RE41   1.0
18    SEPAR      ZR90   0.0       ZR91   0.0       ZR92   0.0
18    SEPAR      ZR94   0.0       ZR96   0.0
```

Fig. 2.13. Example Class Specification for Uranium-Free Fuel

2.4.2. TWODANT Neutronics Solution Option

The TWODANT code is available and can be executed directly from REBUS noting that TWODANT can directly make use of the CCCC interface files. Detailed description of all the TWODANT input data can be found in Reference 12. The cross sections are provided in the ISOTXS dataset, and the geometry and composition specifications can be supplied using the conventional A.NIP3 dataset. For fixed source problems, the inhomogeneous neutron source distribution is provided on the FIXSRC dataset. The solver control input for TWODANT must be provided in a separate file named "twodant.ink" for an eigenvalue problem and "twodant.ins" for a fixed source problem. Fig. 2.14 shows an example TWODANT input file which consists of a set of title cards followed by several "blocks" of data. In this special TWODANT input file, the number of materials "mt" and the number of zones "nzone" should be the same as the number of regions in A.NIP3 since REBUS propagates the compositions such that a unique composition is assigned to each region.

In TWODANT, the reaction rates and fluxes are not normalized consistently with REBUS. Thus, a separate flux and reaction rate normalization is performed internal to REBUS with the RTFLUX file from TWODANT. As a consequence, all regular output edit details from TWODANT are not needed in favor of the DIF3D edits available through REBUS. Also, TWODANT requires a single precision FIXSRC file while REBUS requires a double precision FIXSRC file and thus REBUS does the conversion internally as a convenience to the user.

This capability allows the user to use the REBUS input deck prepared for DIF3D neutronics calculations with very little modifications. Only card type 01 of A.STP027 and card type 03 of A.DIF3D need to be modified. In order to use the TWODANT code for the flux solution, the user needs to change the neutronics solution option specified on the columns 31-36 of A.STP027 type 01 card to 2. In this case, the ISOTXS condensation option specified on the columns 37-42

of the same card should not be used to avoid a problem associated with the higher order scattering cross sections.

```
1
   basic rz-model
/*** block I ***
igeom=7,ngroup=21,isn=04,niso=277,mt=61,nzone=61,
im=10,it=70,jm=11,jt=66,maxlcm=19000000,maxscm=220000,  t
/*** block III ***
lib=isotxs,balxs=0,  t
/*** block IV ***
assign=matls,  t
/*** block V ***
ievt=1,isct=0,ith=0,ibl=1,ibr=0,ibt=0,ibb=0,
epsi=.000005,iitl=10,iitm=200,oitm=100,
fluxp=0,xsectp=0,fissrp=0,sourcp=0,angp=0,raflux=0,
trcor=diag,norm=0,influx=0,insors=0,  t
/*** block VI ***
pted=0,zned=0,igrped=0,  t
```

Fig. 2.14. Sample TWODANT Input File for Eigenvalue Problem (twodant.ink)

3. Mathematical Formulation

The change in spatial distribution of the power in a nuclear reactor as fuel depletes requires the depletion calculation to be performed in conjunction with a whole-core flux calculation. In REBUS, nuclide transmutations are modeled on a three-dimensional, region-dependent basis by use of a diffusion or transport theory flux solver. As discussed in Chapter 2, two basic types of problems are solved: 1) an equilibrium cycle problem to determine the equilibrium condition of a reactor operating under a fixed fuel management scheme, and 2) a non-equilibrium cycle problem to determine the explicit cycle-by-cycle condition of a reactor under a specified periodic or non-periodic fuel management scheme. Operational constraints and fuel management strategies are also considered for both in-reactor and ex-reactor portions of the fuel cycle.

In this chapter, the mathematical formulation is presented for the physical processes discussed in Chapter 2. The coupled system of nuclide transmutation and neutron transport equations for in-reactor depletion calculations is discussed first. This is followed by a description of the mathematical models for various in-reactor and ex-reactor processes, including fuel shuffling, charge and discharge, reprocessing, and re-fabrication. Then, the set of equations for single- and multi-cycle non-equilibrium problems and the boundary conditions and additional constraints for equilibrium cycle problems are discussed.

3.1. Depletion Equations

The reactor fuel depletion is concerned with the long term phenomena that are primarily based upon the interaction of the nuclides distributed in the geometry (nuclide density) and the associated neutron flux distribution. The neutron flux and nuclide density influence each other, and thus the corresponding nonlinear coupling between them makes the analysis inherently complex. To achieve a practical analysis capability, some approximations are necessary that neglect the least important physical phenomena. First, the neutron flux changes arising from short and medium term phenomena – time scales far shorter than the cycle length – are ignored. Transients associated with rapidly saturating fission products (e.g., xenon, samarium) are only considered in a simplified manner. Correspondingly, the need to model prompt and delayed neutrons is eliminated and a linear change in the flux distribution between the beginning and end of a time step is assumed. The spatial distribution of gamma heating is also ignored but the energy deposited is accounted for at the point of emission (lumped in with the neutron heating). With these approximations, the neutron flux is calculated as a sequence of steady-state eigenvalue (or fixed-source driven) solutions of the neutron transport equation where the end of time step flux and nuclide density are simultaneously solved.

3.1.1. Neutron Transport Equation

REBUS obtains the neutron flux distribution by either solving the multigroup transport equation with DIF3D-VARIANT or TWODANT, or by solving the diffusion equation using the DIF3D-FD, DIFD-Nodal, or DIF3D-VARIANT. In the multigroup approximation, the neutron transport in the reactor can be described by the following Boltzmann transport equation:

$$\Omega \cdot \nabla \psi_g(r,\Omega,t) + \Sigma_{tg}(r,t)\psi_g(r,\Omega,t) = Q_g(r,\Omega,t), \quad g = 1,\cdots,G, \tag{3.1}$$

where r, Ω, ant t denote the position, direction, and time, respectively. The macroscopic total cross section Σ_{tg} and the cross section data used in the source term Q_g depend upon time t because the nuclide density varies with time (depletion). Note that no derivative with respect to time is present and thus this is a time-independent equation that is only a function of time due to these changes in the nuclide density. The subscript g is the energy group index, which varies from 1 to G where the group angular flux ψ_g is defined by

$$\psi_g(r,\Omega,t) = \int_{E_g}^{E_{g-1}} dE\psi(r,E,\Omega,t). \tag{3.2}$$

E is the energy variable and $[E_g, E_{g-1}]$ is the energy interval of group g.

For a critical reactor problem, the group source Q_g can be written in terms of macroscopic cross sections as

$$Q_g(r,\Omega,t) = \sum_{g'=1}^{G}\sum_{l=0}^{L}\Sigma_{sl}^{g'\to g}(r,t)\sum_{k=-l}^{l}Y_{lk}(\Omega)\psi_{lkg'}(r,t) + \frac{1}{4\pi k(t)}\sum_{g'=1}^{G}\chi_{g'\to g}\nu\Sigma_{fg'}(r,t)\phi_{g'}(r,t), \tag{3.3}$$

where $\Sigma_{sl}^{g'\to g}$ is the l-th Legendre moment of the scattering cross section from group g' to group g, Y_{lk} is the spherical harmonics, $\nu\Sigma_g$ is the macroscopic neutron production cross section in energy group g, and $\chi_{g'\to g}$ is the fraction of fission neutrons emitted into the group g from a fission in group g'. The scalar flux ϕ_g and the angular flux moments ψ_{lkg} are given by

$$\phi_g(r) = \int_{4\pi} d\Omega'\psi_g(r,\Omega'), \tag{3.4}$$

$$\psi_{lkg}(r) = \int_{4\pi} d\Omega'\overline{Y}_{lk}(\Omega')\psi_g(r,\Omega'), \quad -l \le k \le l, \tag{3.5}$$

where $\overline{Y}_{lk}$ is the complex conjugate of Y_{lk}.

In Eq. (3.3), a time dependent eigenvalue k, called the effective multiplication factor, is introduced to yield a non-trivial solution at each time points. For critical reactor systems, the reactor is always operated at the critical point via control rod movements during the fuel cycle. But for general fuel cycle analysis, such facilities can be modeled well using the displayed eigenvalue formulation. In a subcritical accelerator-driven system, the source term is given by

$$\begin{aligned} Q_g(r,\Omega,t) = &\sum_{g'=1}^{G}\sum_{l=0}^{L}\Sigma_{sl}^{g'\to g}(r,t)\sum_{k=-l}^{l}Y_{lk}(\Omega)\psi_{lkg'}(r,t) + \frac{1}{4\pi}\sum_{g'=1}^{G}\chi_{g'\to g}\nu\Sigma_{fg'}(r,t)\phi_{g'}(r,t) \\ &+S_g(r,\Omega,t) \end{aligned}, \tag{3.6}$$

where $S_g(r,E,t)$ is the independent source provided through the fixed source distribution dataset FIXSRC. As discussed in Section 2.4.1, this independent source is scaled up during the

burn cycle to compensate for the burnup reactivity loss and produce the user-specified power level.

In the diffusion theory approximation, the neutron flux equation can be written as:

$$-\nabla \cdot D_g(r,t)\nabla\phi_g(r,t)+\Sigma_{tg}(r,t)\phi_g(r,t)=Q_g(r,t),\quad g=1,\cdots,G, \tag{3.7}$$

where D_g is the diffusion coefficient. The source term for a critical reactor problem becomes

$$Q_g(r,t)=\sum_{g'=1}^{G}\Sigma_{s0}^{g'\to g}(r,t)\phi_{g'}(r,t)+\frac{1}{k(t)}\sum_{g'=1}^{G}\chi_{g'\to g}\nu\Sigma_{fg'}(r,t)\phi_{g'}(r,t). \tag{3.8}$$

For a subcritical system with a given independent source distribution, it becomes

$$Q_g(r,t)=\sum_{g'=1}^{G}\Sigma_{s0}^{g'\to g}(r,t)\phi_{g'}(r,t)+\sum_{g'=1}^{G}\chi_{g'\to g}\nu\Sigma_{fg'}(r,t)\phi_{g'}(r,t)+S_g(r,t). \tag{3.9}$$

The eigenvalue problem specified by either Eq. (3.1) and Eq. (3.3) or Eq. (3.7) and Eq. (3.8) does not have a unique solution. A unique solution is determined by imposing the following power normalization equation to the flux:

$$\sum_{g=1}^{G}\int_V dV[\kappa_f\Sigma_{fg}(r,t)+\kappa_c\Sigma_{cg}(r,t)]\phi_g(r,t)=P, \tag{3.10}$$

where Σ_{fg} and Σ_{cg} are macroscopic fission and capture cross sections, respectively, κ_f and κ_c are the fission and capture energy conversion factors, respectively [9], and P is the user-specified power level. As stated, these energy conversion factors account for both neutron and gamma related energy deposition in the domain.

The subcritical fixed source problem specified by either Eq. (3.1) and Eq. (3.4) or Eq. (3.7) and Eq. (3.9) has a unique solution at each time point. As stated, in order to achieve the user-specified power level, the independent source intensity is adjusted to satisfy Eq. (3.10). It is noted that for a given source distribution, the power level of a subcritical system is correlated with the multiplication factor k_s of the inhomogeneous system defined earlier in Eq. (2.3) as

$$P(t)=\frac{(\bar{\kappa}_f+\bar{\kappa}_c\bar{\alpha})}{\bar{\nu}(1/k_s-1)}\sum_{g=1}^{G}\int_V dVS_g(r,t), \tag{3.11}$$

where $\bar{\nu}$, $\bar{\alpha}$, $\bar{\kappa}_f$, and $\bar{\kappa}_c$ are the reactor-averaged number of neurons produced per fission, capture-to-fission ratio, fission energy conversion factor, and capture energy conversion factor, respectively, which are defined as

$$\bar{\nu}=\frac{\sum_{g=1}^{G}\int_V dV\nu\Sigma_{fg}(r,t)\phi_g(r,t)}{\sum_{g=1}^{G}\int_V dV\Sigma_{fg}(r,t)\phi_g(r,t)}, \tag{3.12}$$

$$\bar{\alpha} = \frac{\sum_{g=1}^{G}\int_V dV \Sigma_{cg}(r,t)\phi_g(r,t)}{\sum_{g=1}^{G}\int_V dV \Sigma_{fg}(r,t)\phi_g(r,t)}, \tag{3.13}$$

$$\bar{\kappa}_f = \frac{\sum_{g=1}^{G}\int_V dV \kappa_f \Sigma_{fg}(r,t)\phi_g(r,t)}{\sum_{g=1}^{G}\int_V dV \Sigma_{fg}(r,t)\phi_g(r,t)}, \tag{3.14}$$

$$\bar{\kappa}_c = \frac{\sum_{g=1}^{G}\int_V dV \kappa_c \Sigma_{cg}(r,t)\phi_g(r,t)}{\sum_{g=1}^{G}\int_V dV \Sigma_{cg}(r,t)\phi_g(r,t)}, \tag{3.15}$$

For notational simplicity, the following operator form of transport and diffusion equation will be used in the discussions below:

$$\mathbf{T}\psi = \begin{cases} \mathbf{M}\psi - \frac{1}{k}\mathbf{F}\psi = 0, & \text{for a critical reactor problem} \\ \mathbf{M}\psi - \mathbf{F}\psi - S = 0, & \text{for a subcritical fixed source problem} \end{cases}, \tag{3.16}$$

where $\mathbf{M}$ is the migration and loss operator and $\mathbf{F}$ is the fission operator.

3.1.2. Nuclide Transmutation Equations

As discussed in Section 2.1.1, a three-level indexing system is used in REBUS to identify and locate each of the fuel bundles in the in-reactor cycle. With this three-level indexing system, the reactor is divided into a set of spatial regions $\{R_1, R_2, \cdots, R_K\}$, and each region is loaded with a certain material type l. The burned stage of a material is denoted by a stage number τ. Thus, the index triplet (l,τ,k) locates a particular material during any given burn step.

After processing the user specified input data, to account for the region-dependent transmutation of the same material, a unique material type is assigned to a region by duplicating materials and expanding the storage as needed. As discussed in Section 2.1.2, fuels of different stage numbers can be assigned to a single region for a scattered reloading scheme without fuel shuffling and a fuel from a stage can be assigned uniquely to each region for a fuel management scheme with fuel shuffling.

In REBUS, the nuclide transmutation calculations as well as the fuel shuffling and refueling operations are performed on a region-wise basis. REBUS assumes that all of the nuclides in a region are exposed to the region-averaged neutron flux and thus the region-averaged nuclide densities in the nuclide transmutation equations are solved on a region-wise basis. This is termed "region depletion" as opposed to fuel pin depletion. To explain, thermal spectrum lattice analysis is performed with heterogeneous fuel pin configurations and thus the depletion is done to update the nuclide densities within each fuel pin whereas REBUS only deals with the average values for a given homogenized region. With region depletion, the information on the intra-assembly nuclide distributions is lost and only average nuclide densities are calculated for each stage of

each material type. It is noted that the pin-wise distributions of nuclide densities, burnup, and fluence can be approximately reconstructed from the spatial distributions of the neutron flux and nuclide densities [26,27].

If a problem involves I active isotopes (i.e., the transmutation chains are specified for I isotopes with card type 09 of A.BURN), the nuclide density vector at time t of a material type l of stage τ can be represented in vector notation as

$$\mathbf{n}_{l,\tau}(t) = \left[n_{l,\tau,1}(t), n_{l,\tau,2}(t), \cdots, n_{l,\tau,i}(t), \cdots, n_{l,\tau,I}(t) \right]^T, \tag{3.17}$$

where $n_{l,\tau,i}$ is the nuclide density of the i-th active isotope. Note that in this report, a lower case vector $\mathbf{n}$ denotes a nuclide density vector in the unit of atoms/cm^3 and an upper case vector $\mathbf{N}$ denotes a nuclide vector in the unit of atoms. Assuming that a total of L material types are loaded into the reactor and that the l-th material resides in the core during $S(l)$ cycles until it is discharged, the nuclide density vector for all the materials in the reactor at time t can be represented as

$$\mathbf{n}_m(t) = \left\{ \mathbf{n}_{1,1}^T(t) \,|\, \mathbf{n}_{1,2}^T(t) \,|\, \cdots \,|\, \mathbf{n}_{1,S(1)}^T(t) \,|\, \mathbf{n}_{2,1}^T(t) \,|\, \cdots \,|\, \mathbf{n}_{2,S(2)}^T(t) \,|\, \mathbf{n}_{L,1}^T(t) \,|\, \cdots \,|\, \mathbf{n}_{L,S(L)}^T(t) \right\}^T. \tag{3.18}$$

With this notation, the nuclide density vectors of charged and discharged fuels can be written as in Eq. (3.19) and Eq. (3.20), respectively,

$$\mathbf{n}_c = \left(\mathbf{n}_{c,1}^T \,|\, \mathbf{n}_{c,2}^T \,|\, \cdots \,|\, \mathbf{n}_{c,L}^T \right)^T = \left\{ \mathbf{n}_{1,1}^T(0) \,|\, \mathbf{n}_{2,1}^T(0) \,|\, \cdots \,|\, \mathbf{n}_{L,1}^T(0) \right\}^T, \tag{3.19}$$

$$\mathbf{n}_d = \left(\mathbf{n}_{d,1}^T \,|\, \mathbf{n}_{d,2}^T \,|\, \cdots \,|\, \mathbf{n}_{d,L}^T \right)^T = \left\{ \mathbf{n}_{1,S(1)}^T(T_{cl}) \,|\, \mathbf{n}_{2,S(2)}^T(T_{cl}) \,|\, \cdots \,|\, \mathbf{n}_{L,S(L)}^T(T_{cl}) \right\}^T, \tag{3.20}$$

where T_{cl} is the cycle length.

Using the stage density vector defined in Eq. (3.17), the region-averaged nuclide density vector for a region R_k can be calculated with

$$\bar{\mathbf{n}}_{r,k}(t) = \frac{1}{V_k} \sum_{(l,\tau)\in R_k} \mathbf{n}_{l,\tau}(t) V_l, \tag{3.21}$$

where V_k is the volume of region R_k and V_l denotes the volume of material type l. As mentioned above, for a fuel management scheme with fuel shuffling, each region contains only one fuel type of certain stage. In this case, the region density vector in Eq. (3.21) is equal to the corresponding material stage density vector.

Omitting the material, stage, and region indices for simplicity, the transmutation equation for an isotope i in a material l of stage τ loaded in region k is given by

$$\frac{d}{dt}n_i(t)=\sum_{j=1}^{I}\left[\sum_x \gamma_{jx}^i \sum_{g=1}^{G}\sigma_{jxg}(t)\bar{\phi}_{kg}(t)+\gamma_{jd}^i\lambda_j\right]n_j(t)-\left[\sum_{g=1}^{G}\sigma_{iag}(t)\bar{\phi}_{kg}(t)+\lambda_i\right]n_i(t), \tag{3.22}$$

where

$n_i(t)=$ Region averaged atomic number density of nuclide i at time t,

$\sigma_{jxg}(t)=$ Microscopic group g cross section of nuclide j for a reaction type x at time t,

$\gamma_{jx}^i=$ Yield fraction of nuclide i due to reaction x of nuclide j,

$\lambda_j=$ Decay constant of nuclide j,

$\gamma_{jd}^i=$ Yield fraction of nuclide i due to radioactive decay of isotope j,

$\sigma_{iag}(t)=$ Microscopic group g absorption cross section of nuclide i at time t,

$\bar{\phi}_{kg}(t)=$ Group g flux averaged over region k at time t.

Here the absorption reaction of isotope i includes all the reactions specified on type 09 cards of A.BURN that transmute isotope i to other isotopes. The system of transmutation equations for a stage density vector $\mathbf{n}_{l,\tau}(t)$ in region R_k, or simply the region density vector $\bar{\mathbf{n}}_{r,k}(t)$, can be represented in operator form as

$$\frac{d}{dt}\mathbf{n}_{l,\tau}(t)=\mathbf{A}_{l,\tau}[\bar{\phi}_k(t),\sigma(t),\lambda]\mathbf{n}_{l,\tau}(t), \tag{3.23}$$

$$\frac{d}{dt}\bar{\mathbf{n}}_{r,k}(t)=\mathbf{A}_k[\bar{\phi}_k(t),\sigma(t),\lambda]\bar{\mathbf{n}}_{r,k}(t), \tag{3.24}$$

where $\mathbf{A}_k$ denotes the transmutation rate matrix for region k consisting of terms

$$\begin{aligned} a_{ij}(t)&=\sum_x \gamma_{jx}^i \sum_{g=1}^{G}\sigma_{jxg}(t)\bar{\phi}_{kg}(t)+\gamma_{jd}^i\lambda_j \quad (j\neq i),\\ a_{ii}(t)&=-\sum_{g=1}^{G}\sigma_{iag}(t)\bar{\phi}_{kg}(t)-\lambda_i. \end{aligned} \tag{3.25}$$

This transmutation rate matrix $\mathbf{A}$ is termed the "burn" matrix in the REBUS-2 and REBUS-3 manuals [5,6] and the BCD input dataset A.BURN.

A single non-equilibrium cycle analysis for a given initial reactor configuration is completed by solving the transmutation equation in Eq. (3.24) for a specified cycle length T for every region in the reactor together with the neutronics equation in Eq. (3.16). Representing the all the region density vectors by the following column vector:

$$\bar{\mathbf{n}}_r(t)=\mathrm{col}\left[\bar{\mathbf{n}}_{r,1}(t),\bar{\mathbf{n}}_{r,2}(t),\cdots,\bar{\mathbf{n}}_{r,K}(t)\right], \tag{3.26}$$

the initial condition can be represented as

$$\bar{\mathbf{n}}_r(0) = \bar{\mathbf{n}}_{r,0}. \tag{3.27}$$

For a multi-cycle or equilibrium cycle analysis, however, additional equations are required to describe the operations on the fuel such as fuel discharge, shuffling, and loading. The principal difference between a single-cycle and a multi-cycle analysis is the discontinuity in the nuclide density introduced by the shuffling and refueling operations. Therefore, the equations describing these operations can be derived as discontinuity conditions in the nuclide density. The neutron flux in the reactor during refueling or fuel management time is so small that it can be neglected. Therefore, the shuffling and refueling operations will only consider decay processes that occur before the next cycle such that

$$\frac{d}{dt}\mathbf{n}_{l,\tau}(t) = \mathbf{A}(0,0,\lambda)\mathbf{n}_{l,\tau}(t), \quad t \in (T_{cl}, T_r), \tag{3.28}$$

$$\frac{d}{dt}\bar{\mathbf{n}}_k(t) = \mathbf{A}(0,0,\lambda)\bar{\mathbf{n}}_k(t), \quad t \in (T_{cl}, T_r), \tag{3.29}$$

where $T_r = T_{cl} + t_r$ with t_r being the refueling time, and the transmutation rate matrix in Eq. (3.28) and Eq. (3.29) is independent of region. It should be noted that in the current equilibrium cycle analysis, the refueling time t_r is not considered and only the radioactive decays during the discharge cooling, reprocessing, re-fabrication, and preloading storage times are taken into account.

3.1.3. Fuel Shuffling and Refueling

The shuffling and refueling operations can be represented by a discontinuity condition in the nuclide density at T_r of

$$\bar{\mathbf{n}}_r(T_r^+) = \mathbf{S}_d(T_r)\bar{\mathbf{n}}_r(T_r) - \bar{\mathbf{n}}_d(T_r) + \bar{\mathbf{n}}_c(T_r), \tag{3.30}$$

where T_r^+ denotes the beginning of the next cycle, $\mathbf{S}_d(T_r)$ denotes the shuffling operator at T_r, $\bar{\mathbf{n}}_d(T_r)$ is the discharge density vector at T_r, and $\bar{\mathbf{n}}_c(T_r)$ is the charge density vector at T_r. It is noted that the discharge and charge vectors $\bar{\mathbf{n}}_d$ and $\bar{\mathbf{n}}_c$ are the re-ordered discharge and charge density vectors $\mathbf{n}_d$ and $\mathbf{n}_c$ in Eq. (3.19) and Eq. (3.20), respectively. It is noted that for a fuel management scheme with fuel shuffling, the shuffling and discharge operations can be merged into one operator. For example, consider the scattered reloading scheme without fuel shuffling illustrated in Fig. 2.3. If the regions "R201," "R301," and "R302" are numbered 1, 2, and 3, respectively, then the nuclide density discontinuity condition for the fuel management scheme for material type "A" can be written as

$$\begin{bmatrix} \bar{\mathbf{n}}_1(T_r^+) \\ \bar{\mathbf{n}}_2(T_r^+) \\ \bar{\mathbf{n}}_3(T_r^+) \end{bmatrix} = \begin{bmatrix} \mathbf{I} & 0 & 0 \\ 0 & \mathbf{I} & 0 \\ 0 & 0 & \mathbf{I} \end{bmatrix} \begin{bmatrix} \bar{\mathbf{n}}_1(T_r) \\ \bar{\mathbf{n}}_2(T_r) \\ \bar{\mathbf{n}}_3(T_r) \end{bmatrix} - \frac{1}{3} \begin{bmatrix} \mathbf{n}_{A,3}(T_r) \\ \mathbf{n}_{A,3}(T_r) \\ \mathbf{n}_{A,3}(T_r) \end{bmatrix} + \frac{1}{3} \begin{bmatrix} \mathbf{n}_{A,1}(0) \\ \mathbf{n}_{A,1}(0) \\ \mathbf{n}_{A,1}(0) \end{bmatrix}, \tag{3.31}$$

where $\mathbf{I}$ is the $I \times I$ identity matrix and the index pair (A,τ) denotes the stage τ of the material type "A." It is noted that in this example, each region contains the mixture of fuels of stages 1, 2, and 3 with equal volume fractions of $\frac{1}{3}$.

As another example, consider the reloading scheme with fuel shuffling illustrated in Fig. 2.4. In this fuel management scheme, the stage 4 fuel in R302 (region 3) is discharged, and then the stage 3 fuel in R201 (region 1) is moved to R302 (region 3). Subsequently, the stage 2 fuel in R301 (region 2) is moved to R201 (region 1), and a fresh fuel of stage 1 is charged into R301 (region 2). In this problem, the discharge operation can be merged into the shuffling operator. In addition, the region density vector is equal to the corresponding material stage density vector as mentioned above. Therefore, the nuclide density discontinuity condition can be written as

$$\begin{bmatrix} \mathbf{n}_{A,1}(T_r^+) \\ \mathbf{n}_{A,2}(T_r^+) \\ \mathbf{n}_{A,3}(T_r^+) \end{bmatrix} = \begin{bmatrix} 0 & \mathbf{I} & 0 \\ 0 & 0 & 0 \\ \mathbf{I} & 0 & 0 \end{bmatrix} \begin{bmatrix} \mathbf{n}_{A,1}(T_r) \\ \mathbf{n}_{A,2}(T_r) \\ \mathbf{n}_{A,3}(T_r) \end{bmatrix} + \begin{bmatrix} 0 \\ \mathbf{n}_{A,1}(0) \\ 0 \end{bmatrix}. \tag{3.32}$$

The multi-cycle analysis is completed by repeating the single-cycle analyses with the discontinuity condition in the nuclide field at the beginning of each cycle. After completing the first cycle analysis including the decay during the refueling time for a given initial reactor configuration, the initial nuclide density vector for the second cycle is obtained by the discontinuity condition given in Eq. (3.30). The second cycle can then be started with this initial reactor configuration and the process repeats until the last cycle is reached.

3.2. Equations for Ex-reactor Cycle Models

The ex-reactor or external fuel management can be considered in two parts; one is the reprocessing of the discharged fuel and the other is the fabrication of charged fuel. The fuel from reprocessing plants and external feeds are separated into two classes, and the charge fuels are fabricated by mixing the CLASS 1 and CLASS 2 fuels at specified or assumed ratios according to a priority schedule.

3.2.1. Fuel Discharge and Reprocessing

The discharged fuel of material type l will be stored for a specified cooling period to reduce decay heat, and then will be sold directly or delivered to one or more of J reprocessing plants. For each material type l, let z^l denote the volume fraction to be sold directly after the cooling period and d_j^l be the fraction of the unsold volume of the discharged fuel of material type l to be sent to the j-th reprocessing plant (specified with the card type 15 of A.BURN). A $I \times I$

diagonal matrix $\mathbf{Z}^l$ can be defined for the fraction of direct sale and another $I \times I$ diagonal matrix $\mathbf{D}_j^l$ can be defined for the faction of material l distributed to the reprocessing plant j as

$$\mathbf{Z}^l = \text{diag}\{z^l, z^l, \cdots, z^l\} \ , \tag{3.33}$$

$$\mathbf{D}_j^l = \text{diag}\{d_j^l, d_j^l, \cdots, d_j^l\} \ . \tag{3.34}$$

where "diag" denotes a diagonal matrix.

The losses of nuclide i to the waste stream in the j-th reprocessing plant can be considered by the recovery factor r_i^j that represents the fraction of each isotope i recovered in the j-th reprocessing plant (specified using card type 16 of A.BURN). Using these recovery factors, a $I \times I$ diagonal recovery matrix $\mathbf{R}^j$ can be defined for reprocessing plant j as

$$\mathbf{R}^j = \text{diag}\{r_1^j, r_2^j, \cdots, r_I^j\} \ . \tag{3.35}$$

In addition, let V_l denote the active volume of material type l being discharged, and define a $I \times I$ diagonal volume matrix $\mathbf{V}_l$ as

$$\mathbf{V}_l = \text{diag}\{V_l, V_l, \cdots, V_l\} \, . \tag{3.36}$$

Utilizing the preceding matrices $\mathbf{Z}^l$, $\mathbf{D}_j^l$, $\mathbf{R}^j$, and $\mathbf{V}_l$, the output atom vector $\mathbf{N}_{r,jl}$ of reprocessing plant j for discharged material type l (the number of atoms of I active isotopes recovered in a reprocessing plant j from a discharged material type l) can be obtained with

$$\mathbf{N}_{r,jl} = \mathbf{R}^j \mathbf{D}_j^l (\mathbf{I} - \mathbf{Z}^l) \mathbf{V}_l \mathbf{n}_{l,S(l)} \, . \tag{3.37}$$

Eq. (3.37) can be generalized to include all of the discharged material types and all of the reprocessing plants to give an overall reprocessing plant output vector $\mathbf{N}_r$ (in the unit of number of atoms). By summing up all the discharged material types sent to a reprocessing plant j, the output nuclide vector of a reprocessing plant j can be defined as

$$\mathbf{N}_{r,j} = \sum_{l=1}^{L} \mathbf{N}_{r,jl} = \mathbf{R}^j \sum_{l=1}^{L} \mathbf{D}_j^l (\mathbf{I} - \mathbf{Z}^l) \mathbf{V}_l \mathbf{n}_{l,S(l)} \, . \tag{3.38}$$

The output nuclide vector from a reprocessing plant in Eq. (3.38) can be rewritten in terms of the discharge vector $\mathbf{n}_d$ defined in Eq. (3.20) as

$$\mathbf{N}_{r,j} = \mathbf{R}^j \mathbf{D}^j (\mathbf{I} - \mathbf{Z}) \mathbf{V} \mathbf{n}_d \, , \tag{3.38}$$

where

$$\mathbf{D}^j = \left(\mathbf{D}_1^j \,|\, \mathbf{D}_2^j \,|\, \cdots \,|\, \mathbf{D}_L^j \right) , \tag{3.39}$$

$$\mathbf{Z} = \text{diag}\{\mathbf{Z}_1, \mathbf{Z}_2, \cdots, \mathbf{Z}_L\} , \tag{3.40}$$

$$\mathbf{V} = \text{diag}\{\mathbf{V}_1, \mathbf{V}_2, \cdots, \mathbf{V}_L\}, \tag{3.41}$$

and $\mathbf{I}$ is an $(I \cdot L) \times (I \cdot L)$ identity matrix. In Eq. (3.39), the $\mathbf{D}_j^l$ matrices are augmented together to produce the matrix $\mathbf{D}^j$ which is an $I \times (I \cdot L)$ matrix. The overall output nuclide vector $\mathbf{N}_r$ (of size $J \times I$) from all of the J reprocessing plants can be represented as

$$\mathbf{N}_r = \left(\mathbf{N}_{r,1}^T \,|\, \mathbf{N}_{r,2}^T \,|\cdots|\, \mathbf{N}_{r,J}^T\right)^T = \mathbf{RD(I-Z)Vn}_d, \tag{3.42}$$

where

$$\mathbf{R} = \text{diag}\{\mathbf{R}^1, \mathbf{R}^2, \cdots, \mathbf{R}^J\}, \tag{3.43}$$

$$\mathbf{D} = \text{diag}\{\mathbf{D}^1, \mathbf{D}^2, \cdots, \mathbf{D}^J\}. \tag{3.44}$$

3.2.2. Class Separation and External Feeds

As discussed in Section 2.2.3, the output from each reprocessing plant is separated into two classes by means of the separation fractions (specified with card type 18 of A.BURN). Let the factor C_i^j be the fraction of isotope i from reprocessing plant j that will be placed in the CLASS 1 output stream. Then the fraction $(1 - C_i^j)$ represents the fraction of isotope i from reprocessing plant j placed in the CLASS 2 stream. From these fractions, the $I \times I$ separation matrix $\mathbf{C}^j$ for reprocessing plant j is defined as

$$\mathbf{C}^j = \text{diag}\{C_1^j, C_2^j, \cdots, C_I^j\}. \tag{3.45}$$

By generalizing the $\mathbf{C}^j$ matrix to include all the reprocessing plants, an $(I \cdot J) \times (I \cdot J)$ matrix $\mathbf{C}_r$ is defined as

$$\mathbf{C}_r = \text{diag}\{\mathbf{C}^1, \mathbf{C}^2, \cdots, \mathbf{C}^J\}. \tag{3.46}$$

In addition to the J reprocessing plants, the external cycle may also include a total of M external feeds defined with card type 21 of A.BURN. Each feed line m is defined by the volume V_{fm} on a type 21 card, the isotopic composition given by a nuclide density vector $\mathbf{n}_{f,m}$ specified with card type 22, and the isotopic class separation factors C_i^m defined with card type 18. Note that the card type 18 of A.BURN is used to specify the isotopic separation factors for both reprocessing plants and external feeds with different labels. Using the class separation factors, an $I \times I$ separation matrix $\mathbf{C}^m$ is defined for a feed line m as

$$\mathbf{C}^m = \text{diag}\{C_1^m, C_2^m, \cdots, C_I^m\}. \tag{3.47}$$

Similar to the definition of $\mathbf{C}_r$, the external feed class separation matrix is defined to include all the feed lines as

$$\mathbf{C}_f = \text{diag}\{\mathbf{C}^1, \mathbf{C}^2, \cdots, \mathbf{C}^M\}. \tag{3.48}$$

The external feed volume matrix $\mathbf{V}_f$ of dimension $(I \cdot M) \times (I \cdot M)$ is also defined in a similar way to the material volume matrix $\mathbf{V}_l$ in Eq. (3.41) as

$$\mathbf{V}_f = \text{diag}\{\mathbf{V}_{f1}, \mathbf{V}_{f2}, \cdots, \mathbf{V}_{fM}\}, \tag{3.49}$$

where $\mathbf{V}_{fm}$ is the $I \times I$ diagonal matrix

$$\mathbf{V}_{fm} = \text{diag}\{V_{fm}, V_{fm}, \cdots, V_{fm}\}. \tag{3.50}$$

Using the isotopic compositions specified with card type 22 of A.BURN, the external feed supply vector $\mathbf{N}_f$ of length $M \times I$ is defined by

$$\mathbf{N}_f = \mathbf{V}_f \mathbf{n}_f, \tag{3.51}$$

where $\mathbf{n}_f$ is the overall external feed nuclide density vector defined by

$$\mathbf{n}_f = \left[\mathbf{n}_{f,1}^T \,|\, \mathbf{n}_{f,2}^T \,|\, \cdots \,|\, \mathbf{n}_{f,M}^T\right]^T. \tag{3.52}$$

The reprocessing plant output vector $\mathbf{N}_r$ and the external feed supply vector $\mathbf{N}_f$ are each split into two vectors by applying the appropriate class separation matrix as

$$\mathbf{N}_r^1 = \mathbf{C}_r \mathbf{N}_r = \mathbf{C}_r \mathbf{R} \mathbf{D} (\mathbf{I} - \mathbf{Z}) \mathbf{V} \mathbf{n}_d, \tag{3.53}$$

$$\mathbf{N}_r^2 = (\mathbf{I} - \mathbf{C}_r) \mathbf{N}_r = (\mathbf{I} - \mathbf{C}_r) \mathbf{R} \mathbf{D} (\mathbf{I} - \mathbf{Z}) \mathbf{V} \mathbf{n}_d, \tag{3.54}$$

$$\mathbf{N}_f^1 = \mathbf{C}_f \mathbf{N}_f = \mathbf{C}_f \mathbf{V}_f \mathbf{n}_f, \tag{3.55}$$

$$\mathbf{N}_f^2 = (\mathbf{I} - \mathbf{C}_f) \mathbf{N}_f = (\mathbf{I} - \mathbf{C}_f) \mathbf{V}_f \mathbf{n}_f. \tag{3.56}$$

These four vectors $\mathbf{N}_r^1$, $\mathbf{N}_r^2$, $\mathbf{N}_f^1$, and $\mathbf{N}_f^2$ will be used in the fabrication calculations that determine the charge material nuclide density vectors. Note that each sub-vector of these four vectors is of length I and represents the total number of atoms of each isotope that are available for fabrication at a given time.

As mentioned before, each phase of the reprocessing can include cooling time and the reprocessing time. The total atom vectors are modified to take into account the radioactive decay during these periods. This will be discussed in Section 3.3.

3.2.3. Re-fabrication

The re-fabrication phase of the external cycle is concerned with the construction of the delivery matrices $\mathbf{Q}_r$ and $\mathbf{Q}_f$ that represent the fraction of the total number of atoms of each isotope in each reprocessing plant and in each external feed, respectively, which are to be used

in the fabrication of each composition of charged fuels. The construction of $\mathbf{Q}_r$ and $\mathbf{Q}_f$ is achieved by means of a user-specified multi-level priority ordering scheme discussed in Section 2.2.4. The procedure is described here for CLASS 1 where the treatment for CLASS 2 is similar.

The first part of the priority scheme is an absolute order of preference, or priority level, for the use of each reprocessing plant output vector and each external feed vector in the fabrication of each charged fuel material type. The second part of the priority system is a set of distribution fractions at each priority level. These numbers permit the use of a single source of fuel in two or more charged fuel materials at the same priority level. These priority levels and distribution fractions are defined for CLASS 1 using card type 19 of A.BURN.

The actual volume of fuel required for fabrication of material type l is $e_l V_l$ where e_l is the enrichment of material type l and V_l is the active volume, i.e., the total volume of the charged fuel material which is occupied by active isotopes. The total volume of material type l that can possibly be fabricated by use of all the reprocessing plant output or external feed from source j is given by V_j^l. Through the priority system, each material type l may be competing for the atoms available from each plant and/or feed. The volume V_j^l represents the maximum possible volume for each material if all the atoms available were used to fabricate that material. Let a_i^l denote the fabrication density of pure isotope i in material type l given in Eq. (2.1) (specified with card type 13 of A.BURN). If $N_{j,i}$ is the total number of atoms of isotope i available in CLASS 1 from source j, then this maximum available fuel volume for material type l from source j is given by

$$V_j^l = \sum_{i=1}^{I} \frac{N_{j,i}}{a_i^l}. \tag{3.57}$$

The problem is then to find the fraction of the fuel available from each reprocessing plant and external feed, which is needed for fabrication of material l at each priority level 1 through K. When two or more materials require fuel from the same supply at the same priority k, the total amount of available fuel is allocated according to a successive distribution procedure, the starting point of which are the user-specified distribution fraction $\gamma_{j,k}^l$ on type 19 cards. $\gamma_{j,k}^l$ is defined as the fraction of source j to be used in fabricating material type l at priority level k. The purpose of these fractions is to allow a distribution of portions of a fuel supply to the fabrication of two or more different fuels. The amount of fuel required by each of these materials is unknown at the beginning of the problem because the required enrichments remain to be determined. The principal of the algorithm is that at a given priority level the fuel available from each supply is distributed in proportion to the user-specified $\gamma_{j,k}^l$ if all of the materials being fabricated require this amount of fuel. If some materials require less than this amount, the reminder is distributed to those materials which require more than this amount. This

redistribution continues until no more material requires fuel at this priority level or until no fuel remains in the fuel supplies being used at this priority level. The selection procedure then drops to the next priority and proceeds in a similar manner.

The procedure for carrying out this distribution starts at the priority level 1. Consider the distribution at priority level k after first $k-1$ priority levels. Denoting the actual fraction of each supply j used in the fabrication of material l at a priority level k' by $u^l_{j,k'}$, the fraction of supply j that was used for fabrications at higher priority levels can be obtained by summing $u^l_{j,k'}$ over all materials and over all previous priority levels as

$$U_j = \sum_{k'=1}^{k-1} \sum_{l=1}^{L} u^l_{j,k'} . \tag{3.58}$$

For $k=1$, $U_j = 0$. The remaining fraction $1-U_j$ of supply j at priority level k is distributed in proportional to the user-specified distribution fractions $\gamma^l_{j,k}$ at the priority level k. That is, the new set of distribution fractions at priority level k for each supply j is given by

$$\overline{\gamma}^l_{j,k} = \frac{\gamma^l_{j,k}}{\sum_{l=1}^{L} \gamma^l_{j,k}} (1-U_j) . \tag{3.59}$$

Using the new distribution fractions in Eq. (3.59), the available fuel volume $V_{l,k}$ for fabrication of each material l at priority level k from all of the supplies is

$$V_{l,k} = \sum_{j=1}^{J+M} \overline{\gamma}^l_{j,k} V^l_j , \tag{3.60}$$

where V^l_j is the total volume originally available for the makeup of material type l from the fuel supply j. In addition, the amount W^{k-1}_l already supplied for the fabrication of material l at priority level 1 through $k-1$ can also be determined as

$$W^{k-1}_l = \sum_{j=1}^{J+M} V^l_j \sum_{k'=1}^{k-1} u^l_{j,k'} . \tag{3.61}$$

Since the volume of CLASS 1 fuel originally required for the fabrication of material type l is $e_l V_l$, the amount required at the priority level k is $e_l V_l - W^{k-1}_l$.

If the available volume $V_{l,k}$ is greater than the required volume $e_l V_l - W^{k-1}_l$, the fabrication requirements of material l are satisfied. Otherwise, material l still requires more fuel from the supplies for the next priority level. For a material l whose requirement is satisfied, only a fraction of $V_{l,k}$ needs to be used and thus the actual distribution fraction $u^l_{j,k}$ at the priority level k can be determined as

$$u_{j,k}^{l} = \frac{e_l V_l - W_l^{k-1}}{V_{l,k}} \bar{\gamma}_{j,k}^{l} . \tag{3.62}$$

For those materials whose fuel requirements cannot be fully satisfied, all of $V_{l,k}$ is used and thus the actual distribution faction is set to the normalized distribution faction as

$$u_{j,k}^{l} = \bar{\gamma}_{j,k}^{l} , \tag{3.63}$$

and the remaining volume needed to satisfy material l is decreased by the amount of $V_{l,k}$. This completes the first distribution at priority level k.

If all the supply materials at this priority level have been exhausted, there is no alternative but to proceed to the next priority level, i.e., increment k by 1 and begin the above sequence again starting at Eq. (3.59). If supply material remains, the distribution fractions for those materials that have been made up are set to zero so they will not be included in any further distributions. Next, if there is any fuel left in any source and provided some distribution fractions are non-zero, another round of distributions takes place. If there is no material left in any source at this priority level, the process starts at the next priority level. This procedure continues until there are no user-specified non-zero distribution fractions at a priority level.

When the final priority level (i.e., level K) is completed, it is necessary that all materials have been completely fabricated. If this is not the case, the basic assumption that the reactor can be made critical with a fresh loading may be violated. Normally, the user defines an external feed with a very large volume that avoids this difficulty. There remains the possibility that there will be unused fuel atoms in one or more reprocessing plant supplies when fabrication is completed. By convention, these atoms are added to those that are sold.

The final fraction U_j^l of the total fuel volume from each supply j that is to be used for fabrication of material type l is given by the sum over all priority levels of the fraction distributed at each level,

$$U_j^l = \sum_{k=1}^{K} u_{j,k}^{l} . \tag{3.64}$$

These fractions can then be used to determine the number of atoms of each CLASS 1 isotope from each reprocessing plant and external feed supply, which are actually used in the fabrication of material l.

The entire process is then repeated for CLASS 2 feed streams. The CLASS 2 priority scheme operates in an identical fashion except that the required fuel volume for material l is now given by $(1-e_l)V_l$ and thus $N_{j,i}$ in Eq. (3.57) becomes the total number of atoms of isotope i available in CLASS 2.

Let $U^l_{r,j,1}$ and $U^l_{r,j,2}$ be the fractions of the total fuel volume from reprocessing plant j used to fabricate CLASS 1 and CLASS 2 fuels of material l, respectively. Similarly, let $U^l_{f,m,1}$ and $U^l_{f,m,2}$ be the fractions of the total fuel volume from external feed m used to fabricate CLASS 1 and CLASS 2 fuels of material l, respectively. Then the number of atoms $N_{c,l,i}$ of isotope i used in the fabrication of material l is given by

$$N_{c,l,i} = \sum_{j=1}^{J} (U^l_{r,j,1} N^1_{r,j,i} + U^l_{r,j,2} N^2_{r,j,i}) + \sum_{m=1}^{M} (U^l_{f,m,1} N^1_{f,m,i} + U^l_{f,m,2} N^2_{f,m,i}), \tag{3.65}$$

where $N^1_{r,j,i}$ and $N^1_{f,m,i}$ are the total number of atoms of isotope i in CLASS 1 fuel of reprocessing plant j defined in Eq. (3.53) and that of external feed m defined in Eq. (3.55), respectively; $N^2_{r,j,i}$ and $N^2_{f,m,i}$ are the total number of atoms of isotope i of CLASS 2 fuel from reprocessing plant j defined in Eq. (3.54) and that of external feed m defined in Eq. (3.56), respectively.

Using Eq. (3.65), the nuclide vector $\mathbf{N}_{cl}$ for all nuclides used in the fabrication of material type l can be written as

$$\mathbf{N}_{c,l} = \sum_{j=1}^{J} (\mathbf{U}^{l,1}_{r,j} \mathbf{N}^1_{r,j} + \mathbf{U}^{l,2}_{r,j} \mathbf{N}^2_{r,j}) + \sum_{m=1}^{M} (\mathbf{U}^{l,1}_{f,m} \mathbf{N}^1_{f,m} + \mathbf{U}^{l,2}_{f,m} \mathbf{N}^2_{f,m}), \tag{3.66}$$

where $\mathbf{N}_{c,l}$ is a vector of length I and $\mathbf{U}^{l,1}_{r,j}$, $\mathbf{U}^{l,2}_{r,j}$, $\mathbf{U}^{l,1}_{f,m}$, and $\mathbf{U}^{l,2}_{f,m}$ are $I \times I$ diagonal matrices given by

$$\mathbf{N}_{c,l} = \left(N_{c,l,1}, N_{c,l,2}, \cdots, N_{c,l,I}\right)^T, \tag{3.67}$$

$$\mathbf{U}^{l,1}_{r,j} = \text{diag}\{U^{l,1}_{r,j}, U^{l,1}_{r,j}, \cdots, U^{l,1}_{r,j}\}, \tag{3.68}$$

$$\mathbf{U}^{l,2}_{r,j} = \text{diag}\{U^{l,2}_{r,j}, U^{l,2}_{r,j}, \cdots, U^{l,2}_{r,j}\}, \tag{3.69}$$

$$\mathbf{U}^{l,1}_{f,m} = \text{diag}\{U^{l,1}_{f,m}, U^{l,1}_{f,m}, \cdots, U^{l,1}_{f,m}\}, \tag{3.70}$$

$$\mathbf{U}^{l,2}_{f,m} = \text{diag}\{U^{l,2}_{f,m}, U^{l,2}_{f,m}, \cdots, U^{l,2}_{f,m}\}. \tag{3.71}$$

Therefore, the charge nuclide vector $\mathbf{N}_c$ of length $I \times L$ for all the material types to be charged can be determined as

$$\mathbf{N}_c = \left(\mathbf{N}^T_{c,1} \,|\, \mathbf{N}^T_{c,2} \,|\cdots|\, \mathbf{N}^T_{c,L}\right)^T = \mathbf{U}^1_r \mathbf{N}^1_r + \mathbf{U}^2_r \mathbf{N}^2_r + \mathbf{U}^1_f \mathbf{N}^1_f + \mathbf{U}^2_f \mathbf{N}^2_f, \tag{3.72}$$

where $\mathbf{U}^1_r$ and $\mathbf{U}^2_r$ are $(L \cdot I) \times (J \cdot I)$ matrices defined as

$$\mathbf{U}^1_r = \text{diag}\{\mathbf{U}^1_{r,1}, \mathbf{U}^1_{r,2}, \cdots, \mathbf{U}^1_{r,L}\}, \tag{3.73}$$

$$\mathbf{U}_r^2 = \text{diag}\{\mathbf{U}_{r,1}^2, \mathbf{U}_{r,2}^2, \cdots, \mathbf{U}_{r,L}^2\}, \tag{3.74}$$

while $\mathbf{U}_f^1$ and $\mathbf{U}_f^2$ are $(L \cdot I) \times (M \cdot I)$ matrices defined as

$$\mathbf{U}_f^1 = \text{diag}\{\mathbf{U}_{f,1}^1, \mathbf{U}_{f,2}^1, \cdots, \mathbf{U}_{f,L}^1\}, \tag{3.75}$$

$$\mathbf{U}_f^2 = \text{diag}\{\mathbf{U}_{f,1}^2, \mathbf{U}_{f,2}^2, \cdots, \mathbf{U}_{f,L}^2\}. \tag{3.76}$$

The submatrices $\mathbf{U}_{r,l}^1$ and $\mathbf{U}_{r,l}^2$ in Eq. (3.73) and Eq. (3.74) are $I \times (I \cdot J)$ matrices given by

$$\mathbf{U}_{r,l}^1 = \left(\mathbf{U}_{r,1}^{l,1} \,|\, \mathbf{U}_{r,2}^{l,1} \,|\cdots|\, \mathbf{U}_{r,J}^{l,1}\right), \tag{3.77}$$

$$\mathbf{U}_{r,l}^2 = \left(\mathbf{U}_{r,1}^{l,2} \,|\, \mathbf{U}_{r,2}^{l,2} \,|\cdots|\, \mathbf{U}_{r,J}^{l,2}\right), \tag{3.78}$$

and the submatrices $\mathbf{U}_{f,l}^1$ and $\mathbf{U}_{f,l}^2$ in Eq. (3.75) and Eq. (3.76) are $I \times (I \cdot M)$ matrices given by

$$\mathbf{U}_{f,l}^1 = \left(\mathbf{U}_{f,1}^{l,1} \,|\, \mathbf{U}_{f,2}^{l,1} \,|\cdots|\, \mathbf{U}_{f,M}^{l,1}\right), \tag{3.79}$$

$$\mathbf{U}_{f,l}^2 = \left(\mathbf{U}_{f,1}^{l,2} \,|\, \mathbf{U}_{f,2}^{l,2} \,|\cdots|\, \mathbf{U}_{f,M}^{l,2}\right). \tag{3.80}$$

Inserting Eq. (3.53) through Eq. (3.56) into Eq. (3.72), the charge nuclide vector $\mathbf{N}_c$ for all of the material types can be written as

$$\mathbf{N}_c = [\mathbf{U}_r^1\mathbf{C}_r + \mathbf{U}_r^2(\mathbf{I}-\mathbf{C}_r)]\mathbf{RD}(\mathbf{I}-\mathbf{Z})\mathbf{V}\mathbf{n}_d + [\mathbf{U}_f^1\mathbf{C}_f + \mathbf{U}_f^2(\mathbf{I}-\mathbf{C}_f)]\mathbf{V}_f\mathbf{n}_f. \tag{3.81}$$

The nuclide density vector of charged fuels in Eq. (3.19) can be determined by dividing this charge nuclide vector by the material volumes as

$$\mathbf{n}_c = \mathbf{V}^{-1}[\mathbf{U}_r^1\mathbf{C}_r + \mathbf{U}_r^2(\mathbf{I}-\mathbf{C}_r)]\mathbf{RD}(\mathbf{I}-\mathbf{Z})\mathbf{V}\mathbf{n}_d + \mathbf{V}^{-1}[\mathbf{U}_f^1\mathbf{C}_f + \mathbf{U}_f^2(\mathbf{I}-\mathbf{C}_f)]\mathbf{V}_f\mathbf{n}_f. \tag{3.82}$$

This expression gives the relationship between the discharged nuclide density vectors, the external feed nuclide densities, and the nuclide density vector of the fabricated material. By defining the delivery matrices $\mathbf{Q}_r$ and $\mathbf{Q}_f$ that represent the fraction of the total number of atoms of each isotope in each reprocessing plant output and in each external feed line, respectively, Eq. (3.82) can be rewritten as

$$\mathbf{n}_c = \mathbf{Q}_r\mathbf{n}_d + \mathbf{Q}_f\mathbf{n}_f, \tag{3.83}$$

where

$$\mathbf{Q}_r = \mathbf{V}^{-1}[\mathbf{U}_r^1\mathbf{C}_r + \mathbf{U}_r^2(\mathbf{I}-\mathbf{C}_r)]\mathbf{RD}(\mathbf{I}-\mathbf{Z})\mathbf{V}, \tag{3.84}$$

$$\mathbf{Q}_f = \mathbf{V}^{-1}[\mathbf{U}_f^1\mathbf{C}_f + \mathbf{U}_f^2(\mathbf{I}-\mathbf{C}_f)]\mathbf{V}_f. \tag{3.85}$$

As discussed above, the matrices $\mathbf{U}_r^1$, $\mathbf{U}_r^2$, $\mathbf{U}_f^1$ and $\mathbf{U}_f^2$ depend on the charged fuel enrichments and the available amount of nuclides in the reprocessing plants, which in turn

depend upon the discharge nuclide density vector $\mathbf{n}_d$. Therefore, the delivery matrices $\mathbf{Q}_r$ and $\mathbf{Q}_f$ also depend on the charged fuel enrichments and the discharge nuclide density vector $\mathbf{n}_d$. Denoting the charged fuel enrichments of L material types as a vector $\mathbf{e}$ as

$$\mathbf{e} = (e_1, e_2, \cdots, e_L)^T, \tag{3.86}$$

Eq. (3.83) can be rewritten, including the dependency of the delivery matrices $\mathbf{Q}_r$ and $\mathbf{Q}_f$ on the enrichment vector and the discharge nuclide vector, as

$$\mathbf{n}_c = \mathbf{Q}_r(\mathbf{e}, \mathbf{n}_d)\mathbf{n}_d + \mathbf{Q}_f(\mathbf{e}, \mathbf{n}_d)\mathbf{n}_f . \tag{3.87}$$

Eq. (3.87) suggests that the charge density vector is determined uniquely for a given enrichment vector, discharge density vector, and external feed density vector given at least one external feed has enough volume to fabricate all of the required materials.

3.3. Equilibrium Cycle Conditions

An equilibrium cycle implies a reactor condition that is invariant for successive operating cycles under a fixed fuel management scheme and specific operating requirements. The initial reactor configuration is the same for each cycle and the following two-point boundary condition should be satisfied instead of the initial condition in Eq. (3.27):

$$\bar{\mathbf{n}}_r(T_r^+) = \bar{\mathbf{n}}_r(0). \tag{3.88}$$

Inserting the nuclide density discontinuity condition of Eq. (3.30) into Eq. (3.88), the two-point boundary condition in Eq. (3.88) can be written as

$$\bar{\mathbf{n}}_r(0) = \mathbf{S}_d(T_r)\bar{\mathbf{n}}_r(T_r) - \bar{\mathbf{n}}_d + \bar{\mathbf{n}}_c, \tag{3.89}$$

As discussed in Section 3.1.3, the shuffling and discharge operations can be merged into one operator for a fuel management scheme with fuel shuffling. Since the stage number is increased for each burn cycle, Eq. (3.89) can be rewritten in terms of the stage densities as

$$\mathbf{n}_{l,\tau}(0) = \mathbf{n}_{l,\tau-1}(T_r), \quad \tau = 2, \cdots, S(l), \quad l = 1, 2, \cdots, L, \tag{3.90}$$

$$\mathbf{n}_{l,1}(0) = \mathbf{n}_{c,l}, \quad l = 1, 2, \cdots, L. \tag{3.91}$$

When the ex-reactor cycle model is involved, the charge densities are given by Eq. (3.87). Thus Eq. (3.91) can be replaced by

$$\mathbf{n}_c = \mathbf{Q}_r(\mathbf{e}, \mathbf{n}_d)\mathbf{n}_d + \mathbf{Q}_f(\mathbf{e}, \mathbf{n}_d)\mathbf{n}_f, \tag{3.92}$$

The discharge density vector in Eq. (3.92) can be obtained by applying the radioactive decays during the external cycle to the stage density vectors discharged at EOC as

$$\mathbf{n}_d = \left(\mathbf{n}_{1,S(1)}^T(T_r)\mathbf{\Lambda}^T(t_e) \,|\, \mathbf{n}_{2,S(2)}^T(T_r)\mathbf{\Lambda}^T(t_e) \,|\, \cdots \,|\, \mathbf{n}_{L,S(L)}^T(T_r)\mathbf{\Lambda}^T(t_e)\right), \tag{3.93}$$

with the decay matrix exponential

$$\mathbf{\Lambda}(t_e) = \exp[\mathbf{A}(0,0,\lambda)t_e], \tag{3.94}$$

where $\mathbf{A}$ is the transmutation rate matrix defined in Eq. (3.25) and t_e is the total time that elapses in the external cycle.

3.3.1. Cyclic Mode Equilibrium Cycle

An equilibrium cycle that is only constrained by the two-point boundary condition in Eq. (3.90) and Eq. (3.91) for a given charge density vector $\mathbf{n}_c$ is referred to as a "cyclic mode equilibrium" cycle in REBUS. That is, the cyclic mode equilibrium is only concerned with the in-reactor cycle of the entire fuel cycle model and makes no reference or connection to the external cycle. The cyclic mode equilibrium is the converged fuel cycle condition achieved by loading a fixed charge density vector into the reactor at the beginning of every burn cycle, running the reactor for a fixed cycle length, and carrying out the fixed fuel management scheme at the end of every burn cycle. A converged fuel cycle condition is achieved if the discharge density vector is the same after every burn cycle.

For a given initial reactor configuration, the EOC state can be determined by solving the transmutation equation in Eq. (3.24) and the neutronics equation in Eq. (3.16) over a given cycle length T as discussed later in Chapter 4. The stage density vector solutions can formally be written in terms of the exponential functions of the transmutation matrices defined in Eq. (3.23). At cyclic mode equilibrium, these matrix exponentials are functions of the charge density vector and the cycle length, and thus the stage density vector at EOC is

$$\mathbf{n}_{l,\tau}(T) = \mathbf{B}_{l,\tau}(T,\mathbf{n}_c)\mathbf{n}_{l,\tau}(0), \quad \tau = 1,2,\cdots,S(l), \quad l = 1,2,\cdots,L, \tag{3.95}$$

where

$$\mathbf{B}_{l,\tau}(T,\mathbf{n}_c) = \exp\left\{\mathbf{A}_{l,\tau}[\bar{\phi}_k(t),\sigma(t),\lambda]T\right\}. \tag{3.96}$$

As discussed in Section 3.1.2, the transmutation rate matrix $\mathbf{A}_{l,\tau}(\bar{\phi}_k,\sigma,\lambda)$ for stage τ of material l is evaluated using the average flux in region R_k where stage τ of material l is located. In a cyclic mode equilibrium, the time evolution of the neutron flux is determined uniquely for a given charge density vector $\mathbf{n}_c$ and thus the transmutation matrix $\mathbf{B}_{l,\tau}$ depends upon $\mathbf{n}_c$.

Using Eq. (3.95), the cyclic mode equilibrium cycle conditions in Eq. (3.90) can be written as

$$\mathbf{n}_{l,\tau}(0) = \left[\prod_{s=\tau-1}^{1}\mathbf{\Lambda}(t_r)\mathbf{B}_{l,s}(T,\mathbf{n}_c)\right]\mathbf{n}_{c,l}, \quad \tau = 2,3,\cdots,S(l), \quad l = 1,2,\cdots,L, \tag{3.97}$$

where $\mathbf{\Lambda}(t_r)$ is the radioactive decay matrix defined in Eq. (3.94). This matrix accounts for radioactive decay during the shutdown time t_r between burn cycles (card type 03 of A. BURN). Similarly, the discharge density vector can be obtained as

$$\mathbf{n}_d(T,\mathbf{n}_c) = \mathbf{B}_d(T,\mathbf{n}_c)\mathbf{n}_c\,, \tag{3.98}$$

where

$$\mathbf{B}_d(T,\mathbf{n}_c) = \mathrm{diag}\left[\mathbf{\Lambda}(t_e)\prod_{s=S(1)}^{1}\mathbf{\Lambda}(t_r)\mathbf{B}_{1,s}(T,\mathbf{n}_c),\cdots,\mathbf{\Lambda}(t_e)\prod_{s=S(L)}^{1}\mathbf{\Lambda}(t_r)\mathbf{B}_{L,s}(T,\mathbf{n}_c)\right], \tag{3.99}$$

In Eq. (3.99), $\mathbf{\Lambda}(t_e)$ is the radioactive decay matrix defined in Eq. (3.94) with respect to the total time t_e spent in the external cycle.

Equation (3.97) provides the formal solution of stage density vectors for a given charge density vector. Starting from the initial core configuration loaded with the given charge density vector $\mathbf{n}_{l,\tau}$, the burn matrices $\mathbf{B}_{l,\tau}$ and stage density vectors $\mathbf{n}_{l,\tau}$ in Eq. (3.97) can be approximated successively by solving the coupled neutron transport equation in Eq. (3.16) and the nuclide transmutation equation in Eq. (3.24) with the region density iteration method discussed in Section 4.1.1 for a series of burn cycles of fixed length and fuel management scheme until two successive cycle discharge density vectors agree within a desired limit. This method of successive approximation of the cyclic mode equilibrium solution will be discussed in detail in Section 4.2.1.

3.3.2. Cyclic Mode Subject to Burnup Constraint

For given charge density vector, cycle length, and fuel management scheme, the cyclic mode equilibrium cycle solution can be obtained as outlined above, and thus the discharge burnup of each material type can be determined uniquely as a function of charge density vector and cycle length. This discharge burnup is typically limited to reduce chances of fuel failure. In REBUS, the cycle length T can be adjusted such that the highest discharge burnup among the user-specified burnup test groups or material types is less than a specified discharge burnup limit b_0. That is, among all the test groups or material types μ for which a burnup limit is specified, the limiting test group or material type $\hat{\mu}$ with the smallest relative burnup over all paths or test groups is first determined such that

$$\frac{b_0 - b_{d,\hat{\mu}}(T,\mathbf{n}_c)}{b_0} = \min_{\mu}\frac{b_0 - b_{d,\mu}(T,\mathbf{n}_c)}{b_0}\,. \tag{3.100}$$

where $b_{d,\mu}(T,\mathbf{n}_c)$ is the discharge burnup of test group or material type μ for the fixed cycle length T and charge density vector $\mathbf{n}_c$. The cycle length T is then adjusted such that the highest discharge burnup is equal to the specified discharge burnup limit b_0 as

$$b_{d,\hat{\mu}}(T,\mathbf{n}_c) = b_0 \,. \tag{3.101}$$

This cycle length adjustment based upon a discharge burnup limit is an optional capability of REBUS (invoked with card types 05 through 08 of A.BURN).

REBUS calculates the test group burnup in two different ways, depending on the burnup convergence criterion EPSG specified with card type 03 of A.BURN. If EPSG is not negative, the discharge burnup is defined as the ratio of the fission loss of specified fissionable isotopes during the in-core residence time to the initial loading of specified active isotopes. The isotopes to be included in the numerator and denominator are defined by the user with card types 07 and 08 of A.BURN, respectively. If neither of these cards are present, the numerator and denominator sums include all isotopes that undergo the fission reaction. If EPSG is negative, the burnup is defined as the ratio of the fissionable atoms destroyed by all processes to the total fissionable atoms initially present in the fuel.

The burnup test groups are defined with card type 05 of A.BURN as a set of fuel management paths, and the desired burnup limit b_0 in Eq. (3.101) is specified with card type 06. A burnup limit may be specified for a burnup test group and/or a single fuel management path, which translates to the material type that follows that path. For a test group, a single average burnup is calculated over the paths included in the group, whereas for a test path, a separate burnup is computed for each material type to which that path applies.

The cyclic mode equilibrium cycle with the burnup constraint in Eq. (3.101) is referred to as a "cyclic mode subject to burnup constraint" in REBUS. The solution for this type of problem is determined by iteratively adjusting the cycle length to satisfy Eq. (3.101), starting from the initial cycle length (as defined on card type 04 of A.BURN). The cyclic mode equilibrium solution for an assumed cycle length is determined as discussed previously. As necessary, the cycle length is then adjusted such that the burnup of the limiting path or test group is equal to the targeted burnup limit b_0 within the convergence criterion EPSG. The successive approximation method to determine the solution for the cyclic mode equilibrium with a burnup constraint will be discussed more in Section 4.2.2.

3.3.3. Unconstrained Equilibrium Cycle

When the external cycle is involved, the charge density vector is determined by the two-point boundary condition in Eq. (3.92). Inserting Eq. (3.98) into Eq. (3.92), we have

$$\mathbf{n}_c = \mathbf{Q}_r(\mathbf{e},\mathbf{B}_d\mathbf{n}_c)\mathbf{B}_d\mathbf{n}_c + \mathbf{Q}_f(\mathbf{e},\mathbf{B}_d\mathbf{n}_c)\mathbf{n}_f \,. \tag{3.102}$$

For a known charge enrichment vector $\mathbf{e}$ and external feed density vector $\mathbf{n}_f$, Eq. (3.102) provides a nonlinear equation for the charge density vector $\mathbf{n}_c$. The cyclic mode equilibrium problem subject to the burnup constraint in Eq. (3.101) and the external cycle equation in Eq. (3.102) is referred to as an "unconstrained equilibrium cycle" in REBUS.

For given charge enrichment vector $\mathbf{e}$ and external feed vector $\mathbf{n}_f$, the charge density vector can be determined iteratively as

$$\mathbf{n}_c^{(q+1)} = \mathbf{Q}_r(\mathbf{e}, \mathbf{B}_d\mathbf{n}_c^{(q)})\mathbf{B}_d\mathbf{n}_c^{(q)} + \mathbf{Q}_f(\mathbf{e}, \mathbf{B}_d\mathbf{n}_c^{(q)})\mathbf{n}_f, \tag{3.103}$$

where q is the iteration index. The initial charge density vector is fabricated with external feeds only. Using an assumed charge density vector, the discharge density vector can be determined by solving the cyclic mode equilibrium problem subject to the burnup constraint as outlined in Section 3.3.2. A new charge density vector is then obtained by the reprocessing and re-fabrication processes discussed in Section 3.2. With the updated charge density vector, the cyclic mode equilibrium problem subject to a burnup constraint is solved again, and subsequently the charge density vector is updated. This successive approximation of the charge density vector is continued until two successive charge density vectors agree within a specified limit. This successive approximation method will be discussed in Section 4.2.3.

3.3.4. Constrained Equilibrium Cycle

The charge fuel composition can also be selected subject to an additional design constraint. For example, the charge fuel has to contain enough fissile materials to maintaining criticality over a specified cycle length and power settings. In REBUS, the charged fuel composition is adjusted to achieve an un-poisoned multiplication factor at a specified time. For a critical reactor problem, the multiplication factor is the eigenvalue k in Eq. (3.3) or Eq. (3.8). For a sub-critical problem, the multiplication factor is the parameter k_s in Eq. (2.3). The un-poisoned aspect refers to the fact that REBUS applies a critical poison search as directed via input. This additional constraint provides an equation to determine one design parameter related to the charged fuel compositions.

As discussed in Section 2.2.1, the enrichment split strategy to flatten the power distribution in the reactor is specified by the user. Specifically, the enrichment of each material type l is determined by Eq. (2.2), and the initial enrichment e_{l0} and enrichment modification factor δ_l in Eq. (2.2) are specified with card type 12 of A.BURN. The charge enrichment vector in Eq. (3.86) can be written as

$$\mathbf{e} = \mathbf{e}_0[1 + (x - 1.0)\boldsymbol{\delta}], \tag{3.104}$$

where

$$\mathbf{e}_0 = \left(e_{10}, e_{20}, \cdots, e_{L0}\right)^T, \tag{3.105}$$

$$\boldsymbol{\delta} = \left(\delta_1, \delta_2, \cdots, \delta_L\right)^T. \tag{3.106}$$

That is, the charge enrichment vector can be determined by the enrichment search parameter x, and this enrichment search parameter can be determined to satisfy a constraint on the multiplication factor.

Once an unconstrained equilibrium solution is obtained for a given enrichment search parameter, the un-poisoned multiplication factor over the operating cycle can be determined uniquely as a function of the enrichment search parameter and the given external feed density vector as

$$k(t) = k(t;T,x,\mathbf{n}_f)\,. \tag{3.107}$$

Note that the cycle length T is determined in the unconstrained equilibrium cycle problem to satisfy the burnup constraint in Eq. (3.101). Using Eq. (3.104), the burnup constraint in Eq. (3.101) and the two-point boundary condition in Eq. (3.102) can be rewritten in terms of the enrichment search parameter x as

$$b_{d,\mu}(T,x,\mathbf{n}_f) = b_0\,, \tag{3.108}$$

$$\mathbf{n}_c = \mathbf{Q}_r(x,\mathbf{B}_d\mathbf{n}_c)\mathbf{B}_d\mathbf{n}_c + \mathbf{Q}_f(x,\mathbf{B}_d\mathbf{n}_c)\mathbf{n}_f\,. \tag{3.109}$$

In REBUS, the enrichment search parameter x in Eq. (3.107) is determined to achieve a specified un-poisoned multiplication factor k_0 at specified time αT (as a fraction of cycle length, i.e., $0 \le \alpha \le 1$) as

$$k(\alpha T;T,x,\mathbf{n}_f) = k_0\,. \tag{3.110}$$

The enrichment search parameter x is iteratively determined to satisfy Eq. (3.109), starting from the two initial guesses specified on card type 04 of A.BURN. In a problem that does not involve the charge enrichment search, the initial value is used to determine the charged fuel enrichments along with the initial enrichments and enrichment modification factors given on card type 12. The targeted value k_0 of the un-poisoned multiplication factor and the fraction α of the total burn time are also specified on card type 04 of A.BURN. If an unconstrained equilibrium cycle problem is further constrained by the multiplication factor constraint in Eq. (3.110), it is referred to as a "constrained equilibrium" cycle in REBUS. The solution strategy for the constrained equilibrium cycle will be discussed in Section 4.2.4.

3.3.5. Alternative Cycle Length Search

As mentioned in Section 2.1.3, REBUS allows an alternative search method for the cycle length to the burnup constraint in Eq. (3.108). In this method, the cycle length is determined to achieve a specified un-poisoned multiplication factor k_0 at EOC

$$k(T;T,x_1,\mathbf{n}_f) = k_0\,. \tag{3.111}$$

x_1 is the first initial guess for the charge enrichment specified on card type 04 of A.BURN, and k_0 is the desired value of the un-poisoned multiplication factor at EOC specified on card type 27.

In this type of problem, the charge enrichment search parameter is given since the multiplication factor equation in Eq. (3.110) for the enrichment search parameter cannot be used together with Eq. (3.111). Furthermore, the burnup equation in Eq. (3.101) or Eq. (3.108) for the cycle length cannot be used with Eq. (3.111). Therefore, this alternative cycle length search problem can be considered an unconstrained equilibrium problem for a given charge enrichment vector, where the burnup limit equation in Eq. (3.108) is replaced with the equation for the multiplication factor at EOC in Eq. (3.111). Alternatively, this can be considered a constrained equilibrium cycle problem, where the optional burnup limit equation is removed and the multiplication factor equation is used to constrain the cycle length instead of the charge enrichment. For this cycle length search problem, to avoid a search on the charge enrichment parameter and the use of the burnup constraint equation, the burnup convergence criterion EPSG specified on card type 03 and the multiplication factor convergence criterion EPSF specified on card type 04 should be greater than or equal to 1.0.

Equation (3.111) can be solved iteratively for the cycle length using the initial guess specified on card type 03 of A.BURN and the second guess specified with card type 27. This iterative solution method will be discussed in Section 4.2.5.

3.4. Non-equilibrium Cycle Search Problems

The charge enrichment can also be adjusted in non-equilibrium cycle problems to achieve a targeted value of the un-poisoned multiplication factor at a specified time point during the burn cycle. However, only fresh fuel can be introduced in the reactor at the beginning of the problem. Therefore, in order to determine the charge enrichment for a non-equilibrium cycle problem with partial reloading, a multi-cycle problem should first be performed for all cycles up to the cycle of interest. The cycle length can also be adjusted to satisfy the burnup constraint discussed in Section 3.3.2 in the same way as done for an equilibrium cycle problem. Furthermore, the control poison density search can be done in the neutronics module to maintain system criticality at each time node.

In a non-equilibrium cycle problem, the charge density vector $\mathbf{n}_c$ in Eq. (3.108) can be determined from the external feed vector $\mathbf{n}_f$ using

$$\mathbf{n}_c = \mathbf{Q}_f(x, \mathbf{n}_f)\mathbf{n}_f , \tag{3.112}$$

where $\mathbf{Q}_f$ is the external feed delivery matrix in Eq. (3.85) and x is the enrichment search parameter from Eq. (3.104). As in the equilibrium cycle problem, the enrichment search parameter x is determined with the constraint

$$k(\alpha T; T, x, \mathbf{n}_f) = k_0 , \tag{3.113}$$

where k_0 is the targeted value of the un-poisoned multiplication factor and α is the fraction of the total burn time (specified with card type 04 of A.BURN).

If a non-equilibrium recycle capability is invoked, the external feed sources are modified based upon the fuel discharged from specified regions in the burn cycle preceding the last burn step. That is, beginning at burn cycle number 3, the feed isotopes and quantities used for a burn cycle c are determined by the fuel which was discharged from cycle $c-2$. In this case, the charge density vector in Eq. (3.112) becomes

$$\mathbf{n}_c^c = \mathbf{Q}_r(x, \mathbf{n}_d^{c-2})\mathbf{n}_d^{c-2} + \mathbf{Q}_f(x, \mathbf{n}_d^{c-2})\mathbf{n}_f , \tag{3.114}$$

where $\mathbf{n}_c^c$ is the charge density vector of the current cycle c and $\mathbf{n}_d^{c-2}$ is the discharge density vector from cycle $c-2$.

4. Solution Methods

The mathematical formulation of the fuel cycle problems was presented in Chapter 3. The coupled system of nuclide transmutation and neutron transport equations was discussed, and the mathematical models for various in-reactor and ex-reactor processes were discussed. The set of equations for single- and multi-cycle non-equilibrium problems and for four interrelated equilibrium cycle problems were discussed. The methods to solve these equations are discussed in this chapter.

The solution methods for non-equilibrium cycle problems are discussed first, focused on the region density iteration method to solve the coupled neutron and nuclide field equations along with the matrix exponential method to solve the system of transmutation equations. The solution strategy for the equilibrium fuel cycle problem is then discussed. The specific sequence of iterative procedures to obtain the equilibrium solution are described, including the charged fuel enrichment and cycle length search algorithms. It is followed by a brief discussion on non-equilibrium cycle search problems. Various acceleration techniques in obtaining these solutions are also discussed.

4.1. Non-equilibrium Cycle Analysis

A single non-equilibrium cycle analysis for a given initial reactor configuration is completed by simultaneously solving the transmutation equation in Eq. (3.24) for all isotopes in all regions with the neutronics equation defined by Eq. (3.16). For a multi-cycle or equilibrium cycle analysis, the same single-cycle analysis approach is applied with different initial conditions due to fuel discharge, shuffling, and loading operations at the end of the previous cycle. These operations can be represented as discontinuity conditions in the nuclide densities in every spatial region.

The solution methods for non-equilibrium cycle problems are focused solving the coupled neutron and nuclide density equations given earlier in Eq. (3.16) and Eq. (3.24). The region density iteration method to solve the coupled neutron and nuclide field equations is first discussed. This is followed by a discussion of the Taylor expansion method used in the scaling and squaring algorithm to calculate matrix exponentials. Finally, the search algorithms for the cycle length and charge enrichment are discussed.

4.1.1. Region Density Iteration Method

Practical solution methods for the coupled neutron flux and nuclide density equations of Eq. (3.16) and Eq. (3.24) are based upon iteration of existing techniques of solving the decoupled equations rather than attempting to simultaneously solve the equations. In these methods, the burnup cycle of length T is divided into N subintervals (t_{n-1}, t_n), $n = 1, 2, \cdots, N$ (card type 03 of A.BURN). There is no limit to the subintervals for a non-equilibrium problem, but an equilibrium problem is limited to a maximum of four subintervals. The subinterval time step size can also be specified by the user (card type 47 of A.BURN).

Starting from the known initial reactor configuration $\bar{\mathbf{n}}_r(0)$, the neutron flux distribution ϕ_{n-1} at each time node t_{n-1} is determined by solving Eq. (3.16) with a known reactor configuration $\bar{\mathbf{n}}_r(t_{n-1})$, and the reactor configuration $\bar{\mathbf{n}}_r(t_n^-)$ at the end of subinterval is determined by solving the transmutation equation in Eq. (3.24) over the subinterval (t_{n-1}, t_n) using an approximate flux shape. The initial condition for the next time step calculation is obtained by imposing the continuity condition

$$\bar{\mathbf{n}}_r(t_n^+) = \bar{\mathbf{n}}_r(t_n) = \bar{\mathbf{n}}_r(t_n^-), \tag{4.1}$$

where t_n^+ and t_n^- refer to the right and left side of the time node t_n, respectively.

The simplest flux approximation is to use the Euler method which assumes that the flux at the beginning of the subinterval remains constant over the subinterval

$$\phi_g(r,t) = \phi_g(r,t_{n-1}), \quad t \in (t_{n-1}, t_n). \tag{4.2}$$

This approximation is often referred to as the constant flux approximation. A more efficient method is to use a high order polynomial based predictor-corrector method that allows for longer time steps and thus fewer flux calculations. REBUS assumes a linear flux approximation over the interval [5], mostly because this is a good approximation for fast spectrum reactors. This approximation differs from the constant flux approximation in that the reaction rates appearing in the transmutation equation are based upon the average of the beginning and ending interval flux solutions (and nuclide densities). With constant cross sections, the nuclide density is transmuted using the average flux over the subinterval (t_{n-1}, t_n),

$$\bar{\phi}_{n,g}(r) = \frac{1}{2}\left[\phi_g(r,t_{n-1}) + \phi_g(r,t_n)\right], \quad g = 1,2,\cdots,G. \tag{4.3}$$

The transmutation rate matrix $\mathbf{A}$ defined in Eq. (3.24) would then be constructed with this average group flux.

The transmutation rate matrix $\mathbf{A}_k$ for a region R_k is constructed with the region-averaged multi-group flux vector defined as

$$\bar{\phi}_{n,k} = \left(\bar{\phi}_{n,k,1}, \bar{\phi}_{n,k,2}, \cdots, \bar{\phi}_{n,k,G}\right)^T, \tag{4.4}$$

which consists of the average group flux in Eq. (4.3) averaged over region R_k as

$$\bar{\phi}_{n,k,g} = \frac{1}{V_k}\int \bar{\phi}_{n,g}(r)dV = \frac{1}{2}\left[\bar{\phi}_{k,g}(t_{n-1}) + \bar{\phi}_{k,g}(t_n)\right], \quad g = 1,2,\cdots,G. \tag{4.5}$$

It is noted that a bold font is not used for the group flux vector for notational simplicity in the following equations. If burnup-dependent microscopic cross sections are used, the transmutation matrices should be formed with average reaction rates instead of average group fluxes. This is

equivalent to forming the transmutation rate matrix over a subinterval (t_{n-1}, t_n) by the average of the transmutation matrices at t_{n-1} and t_n. Thus in REBUS, the average transmutation rate matrix for a region R_k in Eq. (3.24) is obtained using

$$\bar{\mathbf{A}}_k^n = \frac{1}{2}\left\{\mathbf{A}_k[\bar{\phi}_k(t_{n-1}), \sigma(t_{n-1}), \lambda] + \mathbf{A}_k[\bar{\phi}_k(t_n), \sigma(t_n), \lambda]\right\}. \tag{4.6}$$

Using this average transmutation rate matrix and the known nuclide density vector at the beginning of subinterval, the formal solution of Eq. (3.24) at the end of the subinterval can be obtained using

$$\bar{\mathbf{n}}_{r,k}^n = \bar{\mathbf{n}}_{r,k}(t_n) = \exp[\bar{\mathbf{A}}_k^n(t_n - t_{n-1})]\bar{\mathbf{n}}_k(t_{n-1}) = \exp(\bar{\mathbf{A}}_k^n \Delta t_n)\bar{\mathbf{n}}_{r,k}^{n-1}, \tag{4.7}$$

where $\Delta t_n = t_n - t_{n-1}$. The average transmutation rate matrix $\bar{\mathbf{A}}_k^n$ depends upon the group fluxes $\bar{\phi}_k(t_n)$ which itself is dependent on the nuclide density vectors $\mathbf{n}_{r,k}^n$. Therefore, Eq. (4.7) is a nonlinear equation for $\mathbf{n}_{r,k}^n$ that can be solved iteratively.

These nonlinear equations are solved by what is termed in REBUS as the region density iteration method. In this method, the average transmutation rate matrix over the subinterval is computed and solved by repeatedly solving the transmutation equation and the neutron transport equation for the end of the subinterval as illustrated in Fig. 4.1. The initial condition for the subinterval is either the solution obtained at the end of the previous subinterval or the solution for the beginning of the cycle. This algorithm can be summarized as follows:

(1) Calculate the flux distribution ψ_{n-1} at t_{n-1} by solving the neutron transport equation in Eq. (3.16) using the known region density vector $\bar{\mathbf{n}}_r^{n-1}$. ψ_{n-1} is already available for $n \geq 2$ from solving the preceding subinterval.

(2) For every region R_k, construct the transmutation rate matrix $\mathbf{A}_k^{n-1}$ with the calculated flux ϕ_{n-1} at t_{n-1}.

(3) Compute the initial average matrix $\bar{\mathbf{A}}_k^{n(1)}$ with approximate $\mathbf{A}_k^{n(1)}$. For $n = 1$, $\mathbf{A}_k^{n(1)}$ is assumed equal to $\mathbf{A}_k^{n-1}$. For $n \geq 2$, it is obtained by linear extrapolation of $\mathbf{A}_k^{n-2}$ and $\mathbf{A}_k^{n-1}$ as

$$\mathbf{A}_k^{n(1)} = \mathbf{A}_k^{n-1} + (\mathbf{A}_k^{n-1} - \mathbf{A}_k^{n-2}) = 2\mathbf{A}_k^{n-1} - \mathbf{A}_k^{n-2}. \tag{4.8}$$

The initial average matrix is obtained as

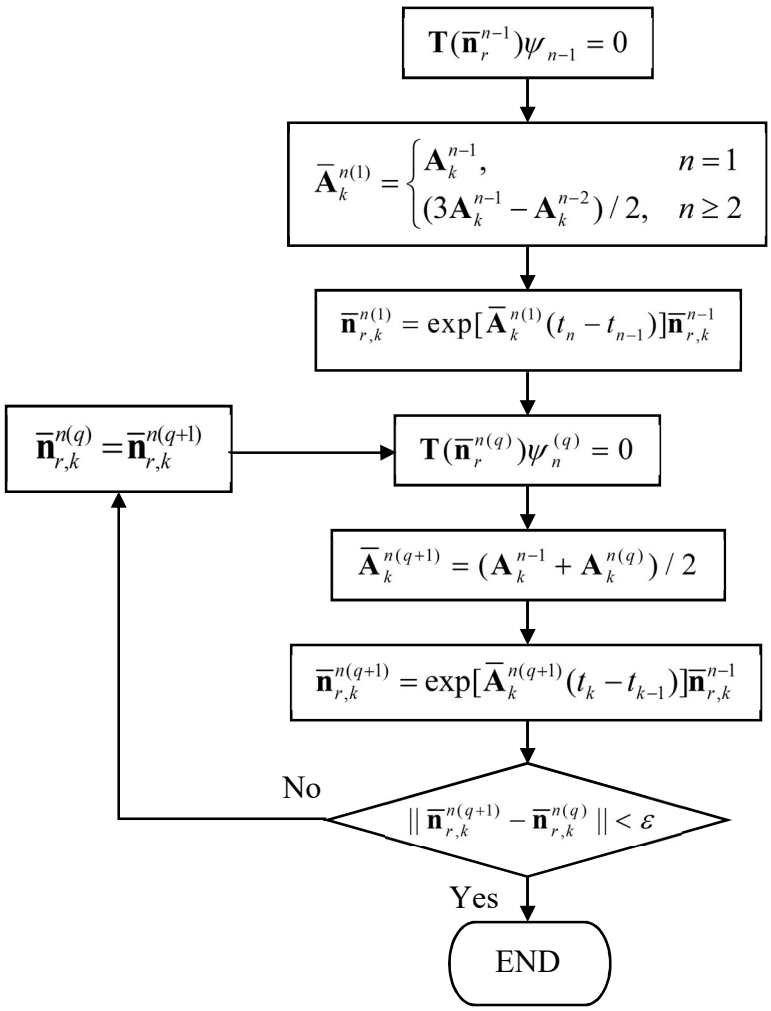


Fig. 4.1. Region Density Iteration Scheme

$$\bar{\mathbf{A}}_k^{n(1)}=\frac{1}{2}(\mathbf{A}_k^{n-1}+\mathbf{A}_k^{n(1)})=\begin{cases}\mathbf{A}_k^{n-1}, & n=1\\ (3\mathbf{A}_k^{n-1}-\mathbf{A}_k^{n-2})/2, & n\ge 2\end{cases}. \tag{4.9}$$

It should be noted that the linear extrapolation in Eq. (4.8) is for equal time step problems. It can yield negative region densities for some problems, in particular thermal reactor problems with burnup-dependent cross sections. This extrapolation can be turned off by adding a negative sign to the maximum number of region density iterations (card type 02 of A.BURN).

(4) Calculate the initial region density vector $\bar{\mathbf{n}}_{r,k}^{n(1)}$ at t_n using the known region density vector $\bar{\mathbf{n}}_{r,k}^{n-1}$ as

$$\bar{\mathbf{n}}_{r,k}^{n(1)}=\bar{\mathbf{n}}_{r,k}^{(1)}(t_n)=\exp[\bar{\mathbf{A}}_k^{n(1)}(t_n-t_{n-1})]\bar{\mathbf{n}}_{r,k}^{n-1}. \tag{4.10}$$

(5) Using the q-th iterative solution $\bar{\mathbf{n}}_r^{n(q)}$ of the region density vector at t_n, calculate the flux distribution $\psi_n^{(q)}$ at t_n by solving the neutron transport equation in Eq. (3.16). Note that this

includes evaluation of the burnup dependent cross sections as discussed in Section 2.1.3 using the calculated region density vector $\overline{\mathbf{n}}_r^{n(q)}$.

(6) Using the calculated flux $\phi_n^{(q)}$, construct the transmutation rate matrix $\mathbf{A}_k^{n(q)}$ at t_n and average the transmutation rate matrix

$$\overline{\mathbf{A}}_k^{n(q+1)} = \frac{1}{2}[\mathbf{A}_k^{n-1} + \mathbf{A}_k^{n(q)}]. \tag{4.11}$$

(7) Using the new transmutation rate matrix, calculate the new region density vector $\overline{\mathbf{n}}_{r,k}^{n(q+1)}$ for every region R_k as

$$\overline{\mathbf{n}}_{r,k}^{n(q+1)} = \overline{\mathbf{n}}_{r,k}^{(q+1)}(t_n) = \exp[\overline{\mathbf{A}}_k^{n(q+1)}(t_n - t_{n-1})]\overline{\mathbf{n}}_{r,k}^{n-1}, \tag{4.12}$$

(8) Check the convergence of the region density vector $\overline{\mathbf{n}}_r^{n(q+1)}$ such that

$$\max_i \frac{|\, n_{r,k,i}^{n(q+1)} - n_{r,k,i}^{n(q)} \,|}{n_{r,k,i}^{n(q)}} \le \varepsilon_n, \quad k = 1, 2, \cdots, K, \tag{4.13}$$

which is constrained by the maximum error for all I active isotopes in all regions. If converged, stop; otherwise repeat steps (5-8) using the updated $\overline{\mathbf{n}}_r^{n(q+1)}$.

The convergence criteria for region densities in Eq. (4.13) is the EPSN given on card type 02 of A.BURN. The maximum number of region density iterations is also specified on the same card as LMAX. If the maximum number of iterations is 0, the region density iteration method reduces to the Euler method noting that the cross sections used at the end of the subinterval are based upon the densities from the beginning of the subinterval and thus not consistent at all follow-on time steps. It is therefore not advisable to use polynomial dependent cross sections with the Euler method. If the maximum number of iterations is set to 1, the region density iteration method is equivalent to a low order predictor-corrector method. A maximum of 5 region density iterations are permitted in REBUS which is based upon extensive experience.

After the region density iteration converges, the average nuclide densities over the subinterval can be calculated using

$$\overline{\overline{\mathbf{n}}}_{r,k}^{n} = \frac{1}{\Delta t_n}\int_{t_{n-1}}^{t_n} \overline{\mathbf{n}}_{r,k}(t)dt = \frac{1}{\Delta t_n}\int_{t_{n-1}}^{t_n} e^{\overline{\mathbf{A}}_k^n t}\overline{\mathbf{n}}_{r,k}^{n-1}dt = \left[\frac{1}{\Delta t_n}\int_{t_{n-1}}^{t_n} e^{\overline{\mathbf{A}}_k^n t}dt\right]\overline{\mathbf{n}}_{r,k}^{n-1} = \mathbf{F}_k^n\overline{\mathbf{n}}_{r,k}^{n-1}, \tag{4.14}$$

where $\mathbf{F}_k^n$ is the average of the transmutation matrix $\mathbf{B}_k^n$ over a subinterval (t_{n-1}, t_n),

$$\mathbf{F}_k^n = F(\overline{\mathbf{A}}_k^n \Delta t_n) = \frac{1}{\Delta t_n}\int_{t_{n-1}}^{t_n} e^{\overline{\mathbf{A}}_k^n t}dt = (\overline{\mathbf{A}}_k^n \Delta t_n)^{-1}(e^{\overline{\mathbf{A}}_k^n \Delta t_n} - \mathbf{I}). \tag{4.15}$$

The average nuclide densities in Eq. (4.14) are used to calculate the average power and conversion ratio over the subinterval. For example, the number of fissions occurring over a

subinterval is computed using these average nuclide densities and the average transmutation rate matrix over the subinterval given in Eq. (4.6).

The region density iteration is executed all N subintervals of burn cycle time and yields a set of "burn" matrices $\mathbf{B}_k^n$ such that

$$\bar{\mathbf{n}}_{r,k}^n = \mathbf{B}_k^n \bar{\mathbf{n}}_{r,k}^{n-1} = \exp[\bar{\mathbf{A}}_k^n (t_n - t_{n-1})] \bar{\mathbf{n}}_{r,k}^{n-1}, \quad k = 1,2,\cdots,K;\ n = 1,2,\cdots,N, \tag{4.16}$$

The total burn operator for region R_k over the burn cycle is thus given by

$$\mathbf{B}_k(T, \bar{\mathbf{n}}_{r,0}) = \prod_{n=N}^{1} \mathbf{B}_k^n, \quad k = 1,2,\cdots,K, \tag{4.17}$$

where the initial region density vector $\bar{\mathbf{n}}_{r,0}$ is introduced to indicate that the neutron flux over the burn cycle is uniquely determined by the initial reactor configuration.

4.1.2. Computational Methods for Matrix Exponential

The solution of the transmutation equation in Eq. (4.7) requires calculation of matrix exponentials. For computation of the matrix exponential, there are about two dozens of possible approaches in the literature from classical results in analysis, approximation theory, and matrix theory [28,29]. These methods can be categorized as series methods, ordinary differential equation methods, polynomial methods, and matrix decomposition methods. Among these various methods, the Taylor series or Padé approximation with a scaling and squaring algorithm is known to be one of the most effective methods [30]. REBUS employs the Taylor series method along with the scaling and squaring algorithm.

The series methods for computing matrix functions are based on the idea that if a scalar function $g(z)$ approximates a scalar function $f(z)$ on the spectrum of a matrix $\mathbf{Z}$, then $g(\mathbf{Z})$ approximates $f(\mathbf{Z})$. Hence, in these methods, standard approximation techniques for the scalar exponential function are directly applied to matrices. In the Taylor series method, the exponential of a transmutation rate matrix can be approximated through the truncation of its Taylor series as

$$\exp(\mathbf{A}\Delta t) \approx \sum_{m=0}^{M} \frac{1}{m!} (\mathbf{A}\Delta t)^m. \tag{4.18}$$

The order of approximation M is chosen large enough so that the truncation error is smaller than the prescribed error tolerance. The order of this approximation is also constrained by the magnitude of the quantities in the transmutation matrix.

In a series method for computing the exponential of $\mathbf{A}\Delta t$, the powers of $\mathbf{A}\Delta t$ are added or subtracted. Hence, if two powers of $\mathbf{A}\Delta t$ have equally large corresponding elements, "catastrophic cancellation" occurs in the finite precision arithmetic [32]. This round-off error difficulty generally increases as the norm $\| \mathbf{A}\Delta t \|$ or the spectral radius $\rho(\mathbf{A}t)$ of $\mathbf{A}t$ increases.

Furthermore, in the case of Taylor and Padé approximations, the computing costs also increase as $\| \mathbf{A}\Delta t \|$ or $\rho(\mathbf{A}t)$ increases since Taylor and Padé approximants are good only near the origin. These difficulties can be controlled by appropriately scaling the matrix by exploiting the fact that $e^{\mathbf{A}\Delta t} = (e^{\mathbf{A}\Delta t/j})^j$. Using this property of the exponential function, the matrix $\mathbf{A}\Delta t$ is first scaled by a power of 2 such that the exponential of the scaled matrix $\mathbf{A}\Delta t / j$ can be computed reliably and efficiently, and then the exponential of the original matrix $e^{\mathbf{A}\Delta t}$ is formed by repeatedly squaring the resulting matrix $e^{\mathbf{A}\Delta t/j}$. This is referred to as the "scaling and squaring" algorithm.

REBUS uses a slightly modified scaling and squaring algorithm based on the following relations:

$$F(\mathbf{W}) = \mathbf{W}^{-1}(e^{\mathbf{W}} - \mathbf{I}), \tag{4.19}$$

$$G(\mathbf{W}) = \frac{1}{2}(e^{\mathbf{W}} + \mathbf{I}) = \frac{1}{2}[2\mathbf{I} + \mathbf{W}F(\mathbf{W})], \tag{4.20}$$

$$F(2\mathbf{W}) = (2\mathbf{W})^{-1}(e^{2\mathbf{W}} - \mathbf{I}) = \frac{1}{2}\mathbf{W}^{-1}(e^{\mathbf{W}} - \mathbf{I})(e^{\mathbf{W}} + \mathbf{I}) = F(\mathbf{W})G(\mathbf{W}), \tag{4.21}$$

$$e^{\mathbf{W}} = \mathbf{I} + \mathbf{W}F(\mathbf{W}). \tag{4.22}$$

where $F(\mathbf{W})$ is the matrix function defined on Eq. (4.15). In this approach, the scaling parameter j is chosen as the smallest power of two for which $\| \mathbf{A}\Delta t \|_\infty / j < 1$. That is, a smallest non-negative integer J is chosen such that

$$2^J > \Delta t \| \mathbf{A} \|_\infty. \tag{4.23}$$

Then $F(\mathbf{W})$ is calculated by the truncated Taylor series as

$$F(\mathbf{W}) = \mathbf{W}^{-1}(e^{\mathbf{W}} - \mathbf{I}) \approx \sum_{m=0}^{M} \frac{\mathbf{W}^m}{(m+1)!}, \tag{4.24}$$

where M is chosen such that

$$\frac{\| \mathbf{W} \|_\infty^M}{(M+1)!} < \varepsilon, \tag{4.25}$$

and ε is a convergence criterion set to 10^{-8}.

Having computed $F(\mathbf{W})$, the relationship between $F(\mathbf{W})$ and $G(\mathbf{W})$ in Eq. (4.21) is used to obtain the sequence

$$F(2\mathbf{W}) = F(\mathbf{W})G(\mathbf{W})$$

$$G(2\mathbf{W}) = \mathbf{I} + \mathbf{W}F(2\mathbf{W})$$

$$F(2^2\mathbf{W}) = F(2\mathbf{W})G(2\mathbf{W})$$
$$\vdots$$
$$F(2^J\mathbf{W}) = F(2^{J-1}\mathbf{W})G(2^{J-1}\mathbf{W}).$$

Thus, the transmutation matrix is obtained as

$$\mathbf{B} = e^{\mathbf{A}\Delta t} = \mathbf{I} + 2^J\mathbf{W}F(2^J\mathbf{W}). \tag{4.26}$$

It is noted that the matrix function $F(2^J\mathbf{W}) = F(\mathbf{A}\Delta t)$ is used to calculate the average nuclide densities over a subinterval as shown in Eq. (4.14).

4.2. Equilibrium Cycle Analysis

As discussed in Section 3.3, the equilibrium cycle problem is a collection of four interrelated intermediate problems: cyclic mode, cyclic mode subject to a burnup constraint, unconstrained equilibrium cycle, and constrained equilibrium cycle. The solutions of these problems are discussed in this section.

4.2.1. Cyclic Mode Equilibrium

As discussed in Section 4.1.1, a set of "burn" matrices $\mathbf{B}_k^n$ in Eq. (4.17) can be obtained by executing the region density iteration for all N subintervals of the burn cycle time. Since stage τ of material l in region R_k is exposed to the same region-averaged neutron flux, the stage densities can be calculated as

$$\begin{aligned}&\mathbf{n}_{l,\tau}^n = \mathbf{B}_{l,\tau}^n\mathbf{n}_{l,\tau}^{n-1} = \exp[\bar{\mathbf{A}}_k^n(t_n - t_{n-1})]\mathbf{n}_{l,\tau}^{n-1},\\ &\quad l = 1,2,\cdots,L;\ \tau = 1,2,\cdots,S(l);\ n = 1,2,\cdots,N\end{aligned}. \tag{4.27}$$

Noting that

$$\mathbf{B}_{l,\tau}^n = \mathbf{B}_k^n \quad \text{for } (l,\tau) \in R_k, \tag{4.28}$$

the total transmutation operator for stage τ of material type l over burn cycle length T is

$$\mathbf{B}_{l,\tau}(T, \bar{\mathbf{n}}_{r,0}) = \prod_{n=N}^{1}\mathbf{B}_{l,\tau}^n, \quad l = 1,2,\cdots,L;\ \tau = 1,2,\cdots,S(l), \tag{4.29}$$

where the initial region density vector $\bar{\mathbf{n}}_{r,0}$ is included to indicate that the neutron flux over the burn cycle is uniquely determined by the initial reactor configuration.

Using the transmutation matrix in Eq. (4.28), the stage densities at the beginning of the next cycle can be obtained as

$$\mathbf{n}_{l,\tau+1}(0) = \mathbf{\Lambda}(t_r)\mathbf{n}_{l,\tau}(T) = \mathbf{\Lambda}(t_r)\mathbf{B}_{l,\tau}(T, \bar{\mathbf{n}}_{r,0})\mathbf{n}_{l,\tau}(0), \quad \tau = 1,2,\cdots,S(l)-1;\ l = 1,2,\cdots,L, \tag{4.30}$$

where $\mathbf{\Lambda}(t_r)$ is the radioactive decay matrix defined in Eq. (3.94). This matrix accounts for the radioactive decay during the shutdown time t_r between burn cycles.

In a cyclic mode equilibrium, every cycle is identical and thus all the stage densities can be calculated using the charged fuel density vectors in Eq. (3.19) as

$$\mathbf{n}_{l,\tau}(0) = \left[\prod_{s=\tau-1}^{1} \mathbf{\Lambda}(t_r)\mathbf{B}_{l,s}(T,\bar{\mathbf{n}}_{r,0})\right]\mathbf{n}_{c,l}, \quad \tau = 1,2,\cdots,S(l);\ l = 1,2,\cdots,L, \tag{4.31}$$

where the sequence of burn matrices is determined by the specific fuel management scheme. Therefore, using Eq. (3.21), the region densities at BOC can be written as

$$\bar{\mathbf{n}}_{r,k}(0) = \frac{1}{V_k}\sum_{(l,\tau)\in R_k}\left\{\left[\prod_{s=1}^{\tau-1} \mathbf{\Lambda}(t_r)\mathbf{B}_{l,s}(T,\bar{\mathbf{n}}_{r,0})\right]\mathbf{n}_{c,l}\right\}V_l, \quad k = 1,2,\cdots,K. \tag{4.32}$$

This is a system of nonlinear equations for the region densities at BOC. This system of equations can be solved iteratively as

$$\bar{\mathbf{n}}_{r,k}^{(q+1)}(0) = \frac{1}{V_k}\sum_{(l,\tau)\in R_k}\left\{\left[\prod_{s=1}^{\tau-1} \mathbf{\Lambda}(t_r)\mathbf{B}_{l,s}(T,\bar{\mathbf{n}}_{r,0}^{(q)})\right]\mathbf{n}_{c,l}\right\}V_l, \quad k = 1,2,\cdots,K, \tag{4.33}$$

where q is the iteration index.

The computational scheme for cyclic mode equilibrium with a given charge density vector $\mathbf{n}_c$ and cycle length T is schematically shown in Fig. 4.2. This algorithm can be summarized as follows:

(1) As an initial guess, all of the stage densities at BOC are assumed equal to the charge density of each material type as

$$\mathbf{n}_{l,\tau}^{(1)}(0) = \mathbf{n}_{c,l}, \quad \tau = 1,2,\cdots,S(l);\ l = 1,2,\cdots,L. \tag{4.34}$$

(2) Using the q-th iterative solution of the stage densities, calculate the region-averaged nuclide densities at BOC for all of the regions in the reactor with

$$\bar{\mathbf{n}}_{r,k}^{(q)}(0) = \sum_{(l,\tau)\in R_k}\mathbf{n}_{l,\tau}^{(q)}(0)(V_l/V_k), \quad k = 1,2,\cdots,K. \tag{4.35}$$

(3) A single non-equilibrium cycle problem is solved for a given reactor configuration at BOC with cycle length T using the methods described in Section 4.1. This yields the burn matrices $\mathbf{B}_{l,\tau}^{(q)}(T,\mathbf{n}_{r,0}^{(q)})$ and the stage density vectors

$$\mathbf{n}_{l,\tau}^{(q+1)}(T) = \mathbf{B}_{l,\tau}^{(q)}(T,\mathbf{n}_{r,0}^{(q)})\mathbf{n}_{l,\tau}^{(q)}(0), \quad \tau = 1,2,\cdots,S(l);\ l = 1,2,\cdots,L, \tag{4.36}$$

$$\mathbf{n}_{l,\tau+1}^{(q+1)}(0) = \mathbf{\Lambda}(t_r)\mathbf{B}_{l,\tau}^{(q)}(T,\mathbf{n}_{r,0}^{(q)})\mathbf{n}_{l,\tau}^{(q)}(0), \quad \tau = 1,2,\cdots,S(l);\ l = 1,2,\cdots,L. \tag{4.37}$$

(4) Check the convergence of the stage density vectors $\mathbf{n}_{l,\tau}^{(q+1)}$ such that

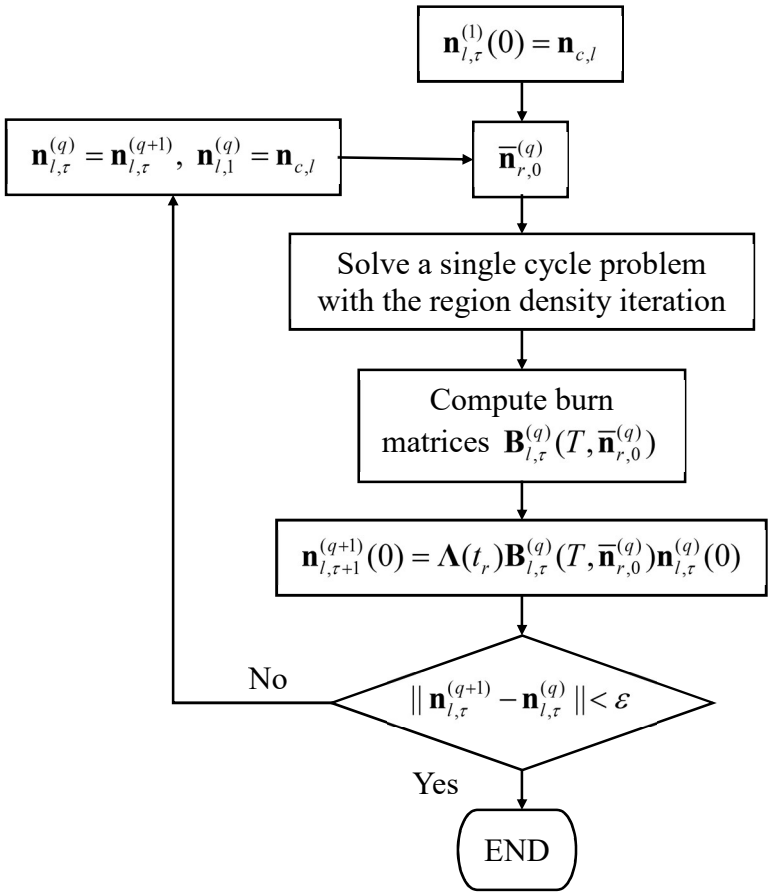


Fig. 4.2. Cyclic Mode Iteration Scheme

$$\max_i \frac{|\, n_{l,\tau,i}^{(q+1)} - n_{l,\tau,i}^{(q)} \,|}{n_{l,\tau,i}^{(q)}} \le \varepsilon_c, \quad l=1,2,\cdots,L;\ \tau=1,2,\cdots,S(l), \tag{4.38}$$

where the maximum is taken over I active isotopes. If converged, stop; otherwise go back to step (2) with the updated stage density vectors

$$\begin{aligned} &\mathbf{n}_{l,\tau}^{(q)}(0)=\mathbf{n}_{l,\tau}^{(q+1)}(0), \quad \tau=2,3,\cdots,S(l), \quad l=1,2,\cdots,L \\ &\mathbf{n}_{l,1}^{(q)}(0)=\mathbf{n}_{c,l}, \quad l=1,2,\cdots,L \end{aligned} \tag{4.39}$$

The convergence criteria for stage densities (EPSC) and the maximum number of cyclic mode iterations (MMAX) are specified on card type 02 of A.BURN. For a non-equilibrium cycle problem, the convergence criteria EPSC should be set to 1.0.

Once the cyclic mode iteration converges, the stage density vectors (and thus the region density vectors) at BOC are uniquely determined for a given charge density vector $\mathbf{n}_c$ and cycle length T. The burn matrices can be considered a function of the cycle length T and the charge density vector $\mathbf{n}_c$ and written as

$$\mathbf{B}_{l,\tau}(T,\bar{\mathbf{n}}_{r,0}) = \mathbf{B}_{l,\tau}(T,\mathbf{n}_c), \quad \tau = 1,2,\cdots,S(l), \quad l = 1,2,\cdots,L\,. \tag{4.40}$$

The stage and discharge densities are then given by

$$\mathbf{n}_{l,\tau}(0) = \left[\prod_{s=\tau-1}^{1} \mathbf{\Lambda}(t_r)\mathbf{B}_{l,s}(T,\mathbf{n}_c)\right]\mathbf{n}_{c,l}, \quad \tau = 1,2,\cdots,S(l)-1, \quad l = 1,2,\cdots,L\,, \tag{4.41}$$

$$\mathbf{n}_{d,l} = \left[\mathbf{\Lambda}(t_e)\prod_{s=S(l)}^{1} \mathbf{\Lambda}(t_r)\mathbf{B}_{l,s}(T,\mathbf{n}_c)\right]\mathbf{n}_{c,l}, \quad l = 1,2,\cdots,L\,, \tag{4.42}$$

where $\mathbf{\Lambda}(t_e)$ is the radioactive decay matrix defined in Eq. (3.94) with the external cycle time t_e.

4.2.2. Cyclic Mode Subject to Burnup Constraint

After obtaining the cyclic mode of the reactor for a charge density vector $\mathbf{n}_c$ and cycle length T, the discharge burnup can be calculated for all the materials in the reactor. The cycle length can be then be adjusted to achieve the desired discharge burnup as described by Eq. (3.101). As noted in Section 3.3.2, the burnup constraint is an option that is invoked by the user by making use of card types 5 through 8 of A.BURN.

The strategy used to meet the burnup constraints is based on the following physical observations [5]. For fast reactors, the burnup constraint is normally that of the maximum permissible discharge burnup in a particular region of the reactor. Under these conditions, the burnup is a monotonically increasing function of time for a constant enrichment. The discharged burnup from the core increases with the cycle length due to the increased residence time.

In order to meet the burnup constraint in Eq. (3.101), the relative burnup error is defined as the relative difference of the computed burnup from the burnup limit or desired burnup for each material type or test group defined by the user. The cycle length is adjusted until the actual error in the burnup of that material or test group with the smallest relative error is zero within the user specified convergence limit. Thus for test group or material type $\hat{\mu}$ that has the minimum burnup error over all test groups or material types μ for which a burnup limit was specified, one can write

$$\frac{b_0 - b_{d,\hat{\mu}}(T)}{b_0} = \min_{\mu} \frac{b_0 - b_{d,\mu}(T)}{b_0}\,, \tag{4.43}$$

where $b_{d,\mu}$ is the discharge burnup of each test group or material μ. The cycle length is adjusted until

$$|\, b_0 - b_{d,\hat{\mu}}(T)\,| \le |\,\varepsilon_g\,|\,. \tag{4.44}$$

This will yield the shortest burn cycle time at which some test group or material has reached the burnup limit.

If Eq. (4.44) is not satisfied by the initial cycle length T, the cycle length is adjusted via linear interpolation of the obtained burnup towards the limiting burnup. An increase of the cycle length by ΔT will increase the total residence time of material type l by $S(l)\Delta T$. Depending on the burnup convergence criterion EPSG specified with card type 03 of A.BURN, the increased loss of fissionable isotopes due to fission or all processes is estimated by

$$\sum_{l\in\hat{\mu}} R_{l,S(l)} S(l)\Delta T\,, \tag{4.45}$$

where $R_{l,S(l)}$ is the destruction rate in stage $S(l)$ of material l and the summation is taken over the single material or the materials in test group $\hat{\mu}$ which have the smallest error. If EPSG is not negative, the fission destruction rate for each material type l is computed using

$$R_{l,S(l)} = \sum_j \left[\sum_{i\in FP} \bar{A}^N_{l,S(l)}(i,j) \Big/ \sum_{i\in FP} \gamma^i_{jf} \right] n_{l,S(l),j}(T) V_l\,. \tag{4.46a}$$

The summation over i is taken over the fission products (FP). The summation over j is taken over the isotopes specified with card type 07 of A.BURN. If no card type 07 is given, it is taken over all fissionable isotopes. $\bar{A}^N_{l,S(l)}(i,j)$ is the element in the i-th row and j-th column of the average transmutation rate matrix $\bar{\mathbf{A}}^N_{l.S(l)}$ in Eq. (4.6), which was defined in Eq. (3.25), and γ^i_{jf} is the yield fraction of fission product i from fission of isotope j. Similarly, $n_{l,S(l),j}(T)$ is the j-th element of the stage density vector $\mathbf{n}_{l,S(l)}$ at EOC, and V_l is the total volume of one stage of material l. If EPSG is negative, the destruction by all processes is computed using

$$R_{l,S(l)} = \sum_j \left[n_{l,S(l),j}(0) - \sum_m B_{l,S(l)}(j,m) n_{l,S(l),m}(0) \right] V_l / T\,, \tag{4.46b}$$

where $B_{l,S(l)}(j,m)$ is the element in the j-th row and m-th column of the total transmutation matrix $\mathbf{B}_{l,S(l)}$ over burn cycle length T defined in Eq. (4.29).

Using the destruction rate in Eq. (4.45), the total burnup for a burn cycle time of $T+\Delta T$ can be estimated and set to the desired burnup as

$$b_0 = b_{d,\hat{\mu}}(T) + \frac{\sum_{l\in\hat{\mu}} R_{l,S(l)} S(l)}{\sum_i n_{c,l,i} V_l} \Delta T\,. \tag{4.47}$$

where $n_{c,l,i}$ is the i-th element of the charge density vector of material l. The summation over i is taken over the isotopes specified with card type 08 of A.BURN. If no card type 08 is given, it is taken over all fissionable isotopes. By solving Eq. (4.47) for ΔT, the new burn cycle estimate can be obtained as

$$T_2 = T_1 + \Delta T = T_1 + \frac{\sum_i n_{c,l,i} V_l}{\sum_{l \in \hat{\mu}} R_{l,S(l)} S(l)} [b_0 - b_{d,\hat{\mu}}(T_1)]. \tag{4.48}$$

Additional burn cycle estimates, up to a total of five, are made by linear interpolation of the preceding two burnup calculations. That is, for $p \geq 3$, the p-th estimate of the cycle length is obtained using

$$T_p = T_{p-1} + \frac{T_{p-1} - T_{p-2}}{b_{d,\hat{\mu}}(T_{p-1}) - b_{d,\hat{\mu}}(T_{p-2})} [b_0 - b_{d,\hat{\mu}}(T_{p-1})]. \tag{4.49}$$

4.2.3. Unconstrained Equilibrium Mode

As discussed in Section 3.3.3, the unconstrained equilibrium mode is found for a given enrichment vector $\mathbf{e}$ by determining the operating time $T = T(\mathbf{e})$ and the charge density vector $\mathbf{n}_c = \mathbf{n}_c(T)$ such that Eq. (3.101) and Eq. (3.102) are satisfied in addition to the cyclic mode equilibrium condition. These quantities are determined by solving Eq. (3.102) with Eq. (3.101) acting as constraint which is shown schematically in Fig. 4.3. Eq. (3.92) and Eq. (3.98) are solved for the charge density vector $\mathbf{n}_c$ and the discharge density vector $\mathbf{n}_d$ where the cycle length T is set to satisfy Eq. (3.101).

The initial charge enrichment guess given on card type 04 of A.BURN is combined with the enrichment details of card type 12 to produce the first charge enrichment vector. The charge density vector and the cycle length are updated in the following manner:

(1) Assuming no discharge fuel, the initial charge density vector is determined from the external feeds using the specified charge enrichment vector

$$\mathbf{n}_c^{(1)} = \mathbf{Q}_f(\mathbf{e}, 0)\mathbf{n}_f. \tag{4.50}$$

(2) By solving a cyclic mode equilibrium problem subject to a burnup constraint, the cycle length T_1 and the following initial discharge vector are determined:

$$\mathbf{n}_d^{(1)} = \mathbf{B}_d(T_1, \mathbf{n}_c^{(1)})\mathbf{n}_c^{(1)}. \tag{4.51}$$

It is noted that the burnup constraint calculation is optional as discussed in Section 3.3.2 and that no change in cycle length may occur.

(3) Using the q-th iterative solution $\mathbf{n}_d^{(q)}$ of the discharge density vector, determine the delivery matrices $\mathbf{Q}_r^{(q)}$ and $\mathbf{Q}_f^{(q)}$ of the discharged fuels and external feeds, respectively, according to the user-specified multi-level priority ordering scheme as discussed in Section 3.2. This process accounts for reprocessing loss, radioactive decay, and direct sale of all discharged fuel.

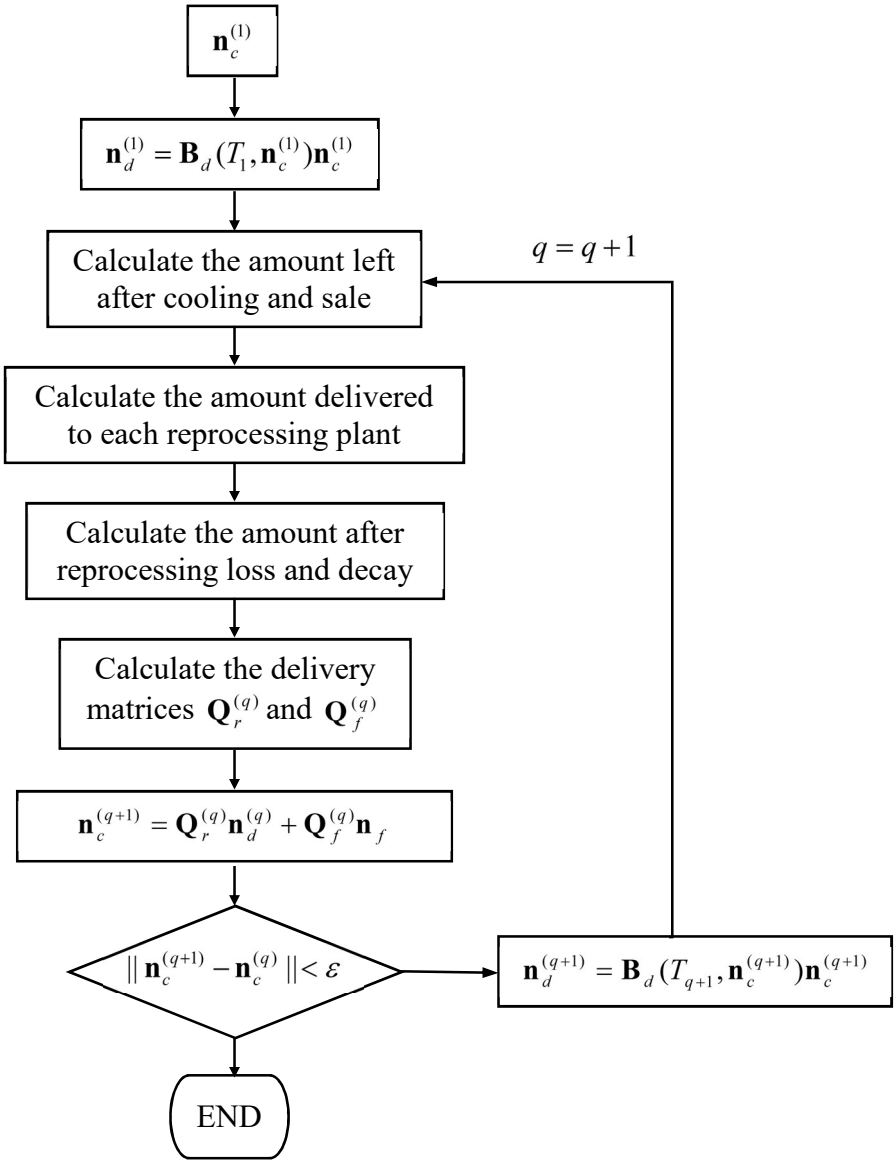


Fig. 4.3. Iterative Solution Scheme for Unconstrained Equilibrium Mode

(4) Using the delivery matrices $\mathbf{Q}_r^{(q)}$ and $\mathbf{Q}_f^{(q)}$, calculate a new charge density vector

$$\mathbf{n}_c^{(q+1)} = \mathbf{Q}_r(\mathbf{e}, \mathbf{n}_d^{(q)})\mathbf{n}_d^{(q)} + \mathbf{Q}_f(\mathbf{e}, \mathbf{n}_d^{(q)})\mathbf{n}_f . \tag{4.52}$$

(5) Check the convergence of the stage density vectors $\mathbf{n}_{l,\tau}^{(q+1)}$ such that

$$\max_i \frac{| n_{c,l,i}^{(q+1)} - n_{c,l,i}^{(q)} |}{n_{c,l,i}^{(q)}} \le \varepsilon_e, \quad l = 1, 2, \cdots, L , \tag{4.53}$$

where the maximum is taken over the I active isotopes. If converged, stop.

(6) If not converged, solve a cyclic mode equilibrium cycle problem subject to the burnup constraint with the new charge vector and determine the new cycle length T_{q+1} and discharge density vector

$$\mathbf{n}_d^{(q+1)} = \mathbf{B}_d(T_{q+1}, \mathbf{n}_c^{(q+1)})\mathbf{n}_c^{(q+1)}. \tag{4.54}$$

Repeat steps (3) to (6) with the updated discharge density vector

$$\mathbf{n}_d^{(q)} = \mathbf{n}_d^{(q+1)}. \tag{4.55}$$

In REBUS, this iterative procedure for the unconstrained equilibrium mode solution is accelerated by ignoring the dependence of the transmutation matrix $\mathbf{B}_d$ on the cycle length T_q and the charge density vector $\mathbf{n}_c^{(q)}$. This works because the unconstrained equilibrium problem is an intermediate step of a constrained equilibrium cycle problem. Thus, the successive iterative steps to obtain the charge density vector $\mathbf{n}_c$ for given charge enrichment vector are given by

$$\mathbf{n}_d^{(q)} = \mathbf{B}_d(T, \mathbf{n}_c^{(1)})\mathbf{n}_c^{(q)}, \tag{4.56}$$

$$\mathbf{n}_c^{(q+1)} = \mathbf{Q}_r(\mathbf{e}, \mathbf{n}_d^{(q)})\mathbf{n}_d^{(q)} + \mathbf{Q}_f(\mathbf{e}, \mathbf{n}_d^{(q)})\mathbf{n}_f, \tag{4.57}$$

$$\mathbf{n}_d^{(q+1)} = \mathbf{B}_d(T, \mathbf{n}_c^{(1)})\mathbf{n}_c^{(q+1)} \quad \vdots \quad . \tag{4.58}$$

These iterations are repeated using the fixed values of cycle length T and charge enrichment vector $\mathbf{e}$ until convergence of the charge enrichment vector $\mathbf{n}_c$ is obtained using Eq. (4.52). The convergence criteria for charge densities EPSE is specified on card type 02 of A.BURN. For a non-equilibrium cycle problem, the convergence criteria EPSE should be set to 1.0. The approximations inherent in Eq. (4.56) through Eq. (4.58) significantly reduces the effort required to obtain the unconstrained equilibrium mode. However, it is essential to note that the constrained equilibrium solutions described in the following section can only be achieved if the charge density vector $\mathbf{n}_c$ satisfies Eq. (4.53) after one iteration at the final step of enrichment search.

4.2.4. Constrained Equilibrium Mode

After obtaining the unconstrained equilibrium mode of the reactor for a fixed charge enrichment vector $\mathbf{e}$, the desired equilibrium solution is obtained by adjusting the charge enrichment vector $\mathbf{e}$ to achieve the user-specified un-poisoned multiplication factor k_0 at the time point αT in the burn cycle as defined in Eq. (3.111). Using the converged transmutation operator $\mathbf{B}_d$, the converged charge density vector $\mathbf{n}_c$, and the cycle length T, the value of the multiplication factor k is calculated at αT. For notational simplicity, the multiplication factor is simply denoted by k for both critical and subcritical fixed source problems, unless otherwise

specified. The value of αT is restricted to an existing time node corresponding to N subintervals of the burn cycle time.

The basic strategy used in obtaining the equilibrium solution is illustrated in Fig. 4.4. The unconstrained equilibrium mode is found for a given initial enrichment vector $\mathbf{e}$ based upon a given x as shown in Eq. (3.104). Thus a reactor cycle length $T = T(x)$ and charge density vector $\mathbf{n}_c = \mathbf{n}_c(x)$ are obtained which satisfy Eq. (3.92), Eq. (3.98), and Eq. (3.101). The enrichment search parameter x is then adjusted as necessary to obtain the desired multiplication factor of Eq. (3.110).

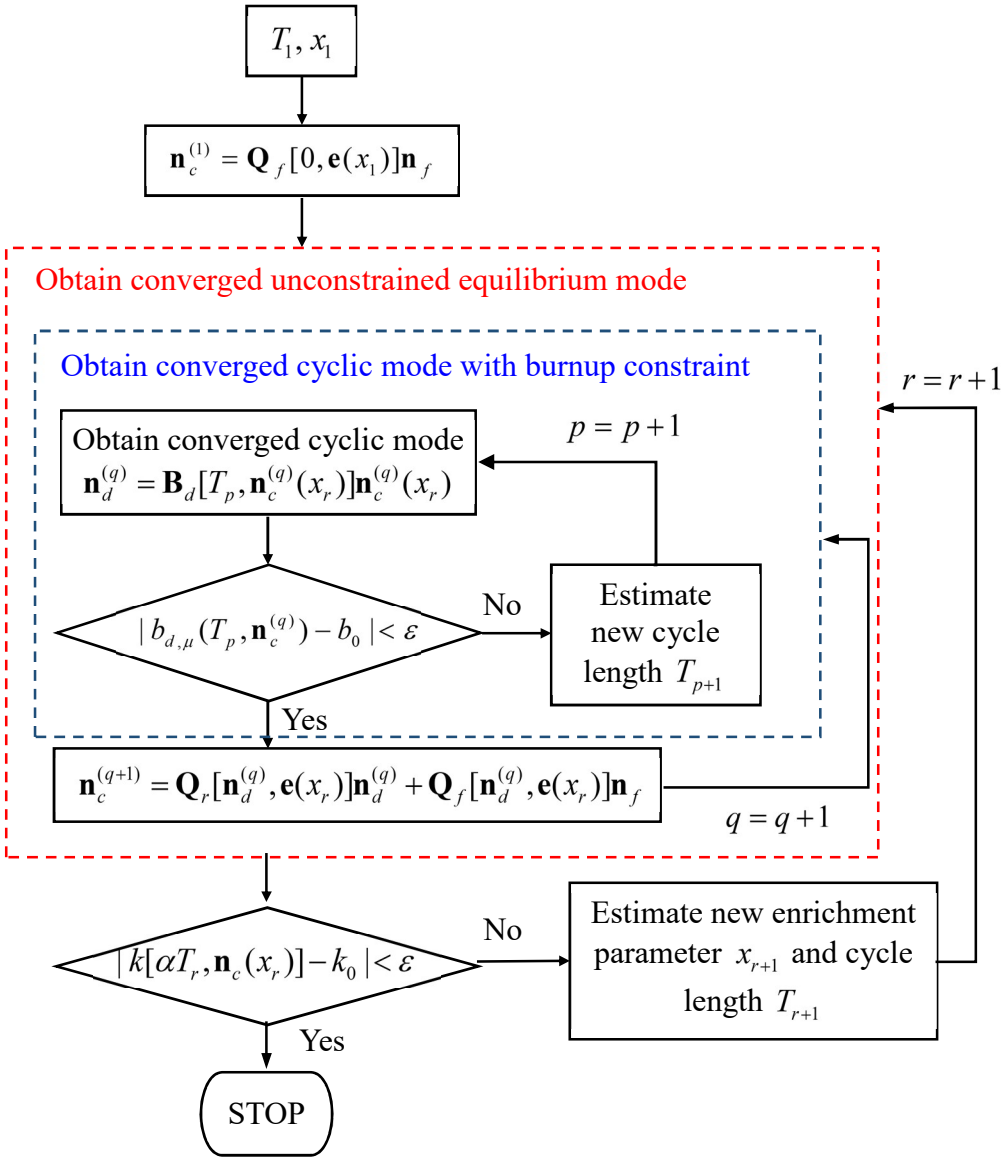


Fig. 4.4. Overall Solution Strategy for Constrained Equilibrium Cycle

The strategy used to obtain the desired enrichments assumes the multiplication factor is a linear function of the enrichment. After calculating the multiplication factor k at a specified time point αT for each of the enrichment search parameters x_1 and x_2 specified on the type 04 card of A.BURN, the new estimate of x is obtained by linear interpolation on the last two points as

$$x_3 = x_1 - \frac{x_1 - x_2}{k_1 - k_2}(k_1 - k_0), \tag{4.59}$$

where $k_r = k(\alpha T; x_r)$ and the subscript r denotes the r-th iteration value. If needed, successive enrichment estimates are obtained by parabolic interpolation on the last three computed points as

$$x_{r+1} = x_r + \frac{(k_{r-2} - k_0)(k_r - k_0)}{k_{r-2} - k_{r-1}}(x_{r-2} - x_{r-1}) + \frac{(k_r - k_0)(k_r - k_{r-1} - k_{r-2} + k_0)}{(k_{r-2} - k_r)(k_{r-1} - k_r)}(x_{r-2} - x_r). \tag{4.60}$$

For problems with fuel reprocessing plants, the following linear interpolation formula is used:

$$x_{r+1} = x_{r-1} - \frac{x_{r-1} - x_r}{k_{r-1} - k_r}(k_{r-1} - k_0). \tag{4.61}$$

In order to estimate the new burn time T_{r+1} constrained by Eq. (3.101), a linear interpolation in the (T, x) plane is used:

$$T_{r+1} = T_r + \frac{T_{r-1} - T_r}{x_{r-1} - x_r}(x_{r+1} - x_r). \tag{4.62}$$

The iteration is terminated when the calculated multiplication factor agrees with the desired value within the specified error criteria

$$\frac{|k_r - k_0|}{k_0} \le \varepsilon_f. \tag{4.63}$$

The convergence criterion for the multiplication factor is the EPSF specified on card type 04 of A.BURN. With the new pair (x_{r+1}, T_{r+1}), the unconstrained equilibrium mode is again obtained using the procedure outlined in the previous section. The whole process is repeated until convergence is reached as outlined in Fig. 4.4.

4.2.5. Alternative Cycle length Search

As discussed in Section 3.3.5, the cycle length of an equilibrium cycle problem can be determined to achieve the user-specified un-poisoned multiplication factor at EOC instead of satisfying the burnup limit equation in Eq. (3.108). In this way, the cycle length is determined for a given charge enrichment vector, and thus it can be considered an unconstrained equilibrium

cycle problem where the burnup limit from Eq. (3.108) is replaced with the equation for the multiplication factor at EOC in Eq. (3.111). This cycle length search capability is invoked by specifying the desired value of the un-poisoned multiplication factor at EOC along with the convergence criterion for the EOC multiplication factor (EPSD) on card type 27 of A.BURN. In this case, the convergence criterion for burnup (EPSG) and the convergence criterion for the multiplication factor (EPSF) should be greater than or equal to 1.0 in order to avoid the search on the charge enrichment parameter and the use of the burnup constraint.

This alternative cycle length search problem can be considered a constrained equilibrium cycle problem where the optional burnup limit equation is removed and the multiplication factor equation is used to constrain the cycle length instead of the charge enrichment. Fig. 4.5 shows the modified solution strategy for the alternative cycle length search problem. First, the unconstrained equilibrium cycle problem is solved for a given cycle length without including the burnup constraint. Then, using the converged charge density vector $\mathbf{n}_c$ and the converged transmutation matrix $\mathbf{B}_d$, the multiplication factor $k(T)$ at EOC is calculated for a given T and compared with the desired value k_0.

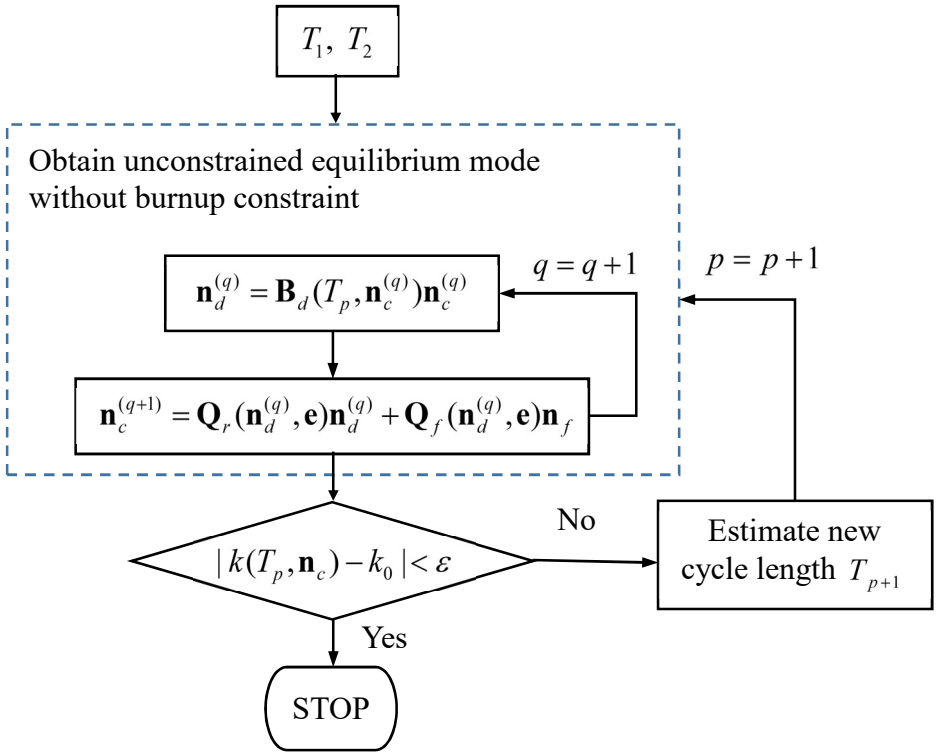


Fig. 4.5. Solution Strategy for Alternative Cycle Length Search

The calculation starts with the two cycle lengths T_1 and T_2 specified on card type 03 and 27 of A.BURN. Later estimates of T are obtained by linear interpolation on the last two points as

$$T_{p+1} = T_p + \frac{T_p - T_{p-1}}{k_p - k_{p-1}}(k_0 - k_p), \tag{4.64}$$

where the subscript p denotes the p-th iteration value. The iteration is terminated when the calculated multiplication factor agrees with the desired value within a specified limit

$$\frac{|k(T_p) - k_0|}{k_0} \le \varepsilon_d . \tag{4.65}$$

The convergence criterion for the multiplication factor at EOC is the EPSD specified on card type 27 of A.BURN.

4.2.6. Non-equilibrium Cycle Search Problems

As discussed in Section 3.4, the cycle length and charge enrichment can be adjusted in the non-equilibrium cycle problem to meet user-specified constraints. As in the equilibrium cycle problem, the cycle length can be adjusted to meet the burnup constraint of Eq. (3.101) and the charge enrichment can be adjusted to achieve a targeted value of the un-poisoned multiplication factor at a specified time point during the burn cycle as defined in Eq. (3.113). A control poison density search can also be done in the neutronics module to maintain system criticality at each time point. The same approach used in obtaining the converged equilibrium solution is used in the non-equilibrium cycle search problem or the constrained non-equilibrium cycle problem.

The main difference between a non-equilibrium search problem and a constrained equilibrium cycle problem is that the cyclic mode iteration is skipped. In a non-equilibrium cycle problem, the stage densities are uniquely determined by the specific fuel management procedure carried out after each burn cycle, and thus the cyclic mode iteration to determine stage densities is not needed. The overall solution strategy for the constrained equilibrium cycle can be applied to non-equilibrium cycle search problems by setting the maximum number of cyclic mode iterations (MMAX) to 1 or the stage density convergence criterion (EPSC) to a value greater than or equal to 1.0, both of which are specified on card type 02 of A.BURN.

The optional burnup limit calculation is invoked by using card types 5 through 8 of A.BURN. With this input, the cycle length is adjusted to satisfy the burnup limit of Eq. (101) as described in Section 4.2.2. The charge enrichment search is performed as described in Section 4.2.4 with two starting guesses x_1 and x_2 specified on card type 04 of A.BURN. In order to determine the charge enrichment of fresh assemblies for a non-equilibrium cycle problem with partial reloading, a multi-cycle problem should first be performed. This problem should proceed from the first cycle loaded with all fresh fuel assemblies up to the cycle of interest for the enrichment search. While an alternative enrichment search capability has been developed [20] that does not require this pre-calculation, it is not presently available in REBUS.

4.3. Acceleration Techniques

Direct application of the iterative strategies presented in the preceding sections can require significant iteration to obtain the converged equilibrium solution. In particular, the charge enrichment search procedure has been observed to take >> 10 iterations to yield a converged charged fuel enrichment for an equilibrium cycle. Since each iteration involves the full computation of the equilibrium cycle with multiple diffusion/transport calculations, one can understand that this constitutes a significant computational burden. To reduce this burden, REBUS solves the equilibrium in three levels with only the last one invoking the full search strategy described in Section 4.2.

The multi-level approach consists of a preliminary search, an intermediate search, and a final search procedure [5,6]. The first two search levels are simplifications of the general strategy to remove some of the less impactful parts of the fuel cycle calculation. For non-equilibrium cycle search problems, the intermediate search level is skipped and only the preliminary and final search levels are used. To reduce the number of region density iterations, the region density vectors are accelerated with a linear extrapolation scheme. Finally, in an effort to reduce the time spent solving the diffusion/transport problem, REBUS stores the flux solution computed at each time node for use as the initial flux solution guess in the neutronics calculation for the next pass.

It should be noted that an enhanced search algorithm for the charge enrichment in equilibrium cycle problems was recently developed [33] but it has not been implemented to the production version of REBUS. This enhanced algorithm is based upon the idea of minimizing the number of enrichment estimates by allowing drastic enrichment changes and by optimizing the current search algorithm of REBUS. Test results with three equilibrium cycle problems with recycling, without recycling, and of high discharge burnup showed that this algorithm is able to produce a converged solution regardless of the initial guesses and reduce the number of flux calculations significantly compared to the current search algorithm. It is also noted that this enhanced search algorithm was further optimized for the application to fixed-source equilibrium cycle problems [34].

4.3.1. Three Levels of Search Procedures

For an enrichment parameter search, barring a good guess by the user, the initial enrichment parameters are significantly different from the final converged value and thus it is not necessary to fully converge the fuel cycle details. In this manner, the main performance improvement is achieved in the three search levels through the progressively increased number of iterations for the region density, cyclic mode, and external cycle iterations and tightened convergence criteria for the flux calculation [5].

Preliminary Search

In the preliminary search level, each cyclic mode equilibrium solution is approximately obtained using at most 2 region density iterations and 1 cyclic mode iteration. One pass through

the external cycle can be optionally performed with specific card type 01 input in A.STP027. In addition to these changes, the entire cycle length is represented as a single time interval thereby ignoring the user-specified number of sub-intervals. No poison control density searches are performed in the preliminary search.

The calculation is initiated by charging the reactor with materials made up from the specified external feeds and reprocessing plant outputs. Note that the same charge $\mathbf{n}_{l,1} = \mathbf{n}_{c,l}$ is used in every stage of a material type l. That is, $\mathbf{n}_{l,\tau} = \mathbf{n}_{l,1}$, $\tau = 1,2,\cdots,S(l)$ for each material type l. With this initial loading, a neutronics solution at BOC and EOC is made to obtain a set of preliminary transmutation operators $\mathbf{B}_{l,1}$ for $l = 1,2,\cdots,L$. These operators are then used to compute the approximate stage densities of each material type as

$$\mathbf{n}_{l,\tau}(T) = [\mathbf{B}_{l,1}(T)]^{\tau}\mathbf{n}_{l,1}, \quad l = 1,2,\cdots,L;\ \tau = 1,2,\cdots,S(l). \tag{4.66}$$

The reactor is then reloaded with these new stage density vectors and the BOC and EOC neutronics solutions are obtained again using the cyclic mode strategy described by Fig. 4.2. To obtain an estimate of the enrichment needed to give the desired un-poisoned multiplication factor k_0 at time αT, the multiplication factor is assumed to be a linear function of time from BOC to EOC. With this assumption and the actual change in k, the necessary multiplication constant at time zero, $k_d(0)$ needed to give $k_0(\alpha T)$ is calculated by linear back extrapolation of $k(T)$ as

$$k_d(0) = k_0(\alpha T) + \frac{\Delta k}{T}\alpha T. \tag{4.67}$$

An enrichment search to obtain $k_d(0)$ is then initiated. If applicable, the burn cycle time T is also adjusted to give the desired burnup b_0.

If the option for one pass through the external cycle in the preliminary search is specified with the card type 01 of A.STP027, the discharge density vector $\mathbf{n}_d = \mathbf{B}_d\mathbf{n}_c$ is passed through one iteration of the external cycle in combination with the new enrichment vector to give a new charge vector $\mathbf{n}_c$. Using this charge density vector and the previously calculated set of transmutation matrices $\mathbf{B}_{l,1}$, a new density distribution at time zero is computed and a neutronics solution to obtain $k_d(0)$ is initiated. The value $k(T)$ of the multiplication factor at EOC is also computed and thus a new enrichment can be computed. These steps are repeated until the desired multiplication factor $k_d(0)$ is achieved as

$$\frac{|k(0) - k_d(0)|}{k_d(0)} \le \varepsilon_f, \tag{4.68}$$

where ε_f is the user-specified convergence criterion on card type 04 of A.BURN.

In equilibrium problems with very high discharge burnups (greater than 20%), the enrichment and burn cycle length searches exhibit extremely slow convergence or even non-convergence. The problem convergence is greatly improved by performing additional cyclic mode iterations [5] at various stages during the calculation. The user may invoke this high burnup mode with proper card type 01 input in A.STP027. In high burnup problems, the first few values of the multiplication factor are far away from the converged value because of the un-converged stage densities, and thus the DIF3D (or TWODANT) eigenvalue convergence criteria is temporarily increased by a factor of 50.

As discussed in Section 4.2.4, a new estimate for the charged fuel enrichment is determined by a linear or quadratic interpolation of the latest two or three enrichments and corresponding multiplication factors. This estimation is based on the assumption that the multiplication factor is a monotonic function of the charge enrichment search parameter. After two values of the enrichment are determined, the next estimate is obtained by linear interpolation. For problems with fuel reprocessing plants, the successive estimates of the enrichment search parameter are obtained via linear interpolation of the last two enrichment search parameters. For problems without fuel reprocessing plants, a quadratic interpolation over the last three enrichment search parameter is used.

The current search algorithm imposes two conditions on the enrichment search parameter: 1) the maximum allowable change is 10 percent of the preceding enrichment parameter, and 2) the enrichment should remain between 0.0 and 1.0. The first limitation helps the convergence of the cyclic mode equilibrium calculation for a given enrichment since the stage densities corresponding to the preceding enrichment are used as the initial guesses for the stage densities for the current enrichment. However, in several examples it has been observed that this can increase the number of enrichment parameter iterations when the user-specified enrichment guesses are far away from the final solution. Hence good guesses by the user are beneficial.

The second condition is logical as the specified initial enrichments e_{0l} in Eq. (3.105) and the enrichment modification factors δ_l in Eq. (3.106) require that the enrichment search parameter be between the lower limit x_L and the upper limit x_U:

$$x_L = \max_l (1 - 1/\delta_l) . \tag{4.69}$$

$$x_U = \min_l [1 + (1/e_{0l} - 1)/\delta_l] . \tag{4.70}$$

where the maximum and minimum are taken over all material types L. The enrichment search procedure allows the estimated enrichment parameter x to be calculated outside of the bounds 10 times before it causes an abort of the search procedure. If one of the bounds is violated, the enrichment parameter is adjusted to be 5% lower than the smallest guess x if the lower bound was violated and 5% higher than the largest guess x if the upper bound was violated. If the adjusted enrichment parameter still violates the enrichment bounds (enrichment factor was

already very close to the bounds) then the search procedure is aborted. This approach still allows some problems to converge but can have a dramatic impact on the computational cost of the search algorithm.

Intermediate Search

If the enrichment parameter converges at the preliminary search level, the intermediate search is initiated with refined computational models to obtain a better estimate of the pair (x,T) giving the constrained equilibrium solution. Specifically, the time domain is divided into the user-specified number of subintervals and full external cycle iterations are made. For normal problems, the region density and cyclic mode iterations are limited to 1. For the high burnup cases, the cyclic mode iteration is set to the user inputted value. No poison control density searches are performed in the intermediate search.

Final Search

Using the enrichment, burn cycle length, and transmutation matrices obtained in the intermediate search procedure, the constrained equilibrium solution is then found using the full search procedure. The cyclic mode, region density, and external cycle iteration limits are all set to the user inputted values. At this level, poison control searches are done in the neutronics module to maintain system criticality at each of the $N+1$ time nodes. The final edits, which have been suppressed up to this point, are printed showing the equilibrium compositions, burnups, breeding ratios, etc. These edits are described in Chapter 5.

4.3.2. Extrapolation Procedures

Region Density Extrapolation for Region Density Iteration

In the discussion in Section 4.1.1, the region density iterations were continued until each region density vector satisfies the inequality condition in Eq. (4.11). To reduce the number of region density iterations, the convergence of the region density vector $\overline{\mathbf{n}}_{r,k}^{n}$ in each region R_k at time t_n is accelerated via linear extrapolation for $q=2$ and 4. It should be noted that $q=5$ is the maximum value permitted. The purpose of this extrapolation is to obtain an estimate of the converged density vector $\overline{\mathbf{n}}_{r,k}^{n}$ for region R_k.

The region density extrapolation is based upon the assumption that the iterates $\overline{n}_{r,k,i}^{n(q)}$ of the region-averaged atom density $\overline{n}_{r,k,i}^{n}$ of isotope i in region R_k can be expressed as a geometric series. Under this assumption, the iterates $\overline{n}_{r,k,i}^{(q)}$ and $\overline{n}_{r,k,i}^{(q-1)}$ can be expressed as

$$\overline{n}_{r,k,i}^{n(q)} = \overline{n}_{r,k,i}^{n} + a_{k,i,1}w_{k,i,1}^{q} + a_{k,i,2}w_{k,i,2}^{q} + \cdots, \tag{4.71}$$

$$\overline{n}_{r,k,i}^{n(q-1)} = \overline{n}_{r,k,i}^{n} + a_{k,i,1}w_{k,i,1}^{q-1} + a_{k,i,2}w_{k,i,2}^{q-1} + \cdots, \tag{4.72}$$

where $1 > w_{k,i,1} > w_{k,i,2} > w_{k,i,3} > \cdots$.

By solving these equations for $\overline{n}_{r,k,i}$ and $a_{k,i,1}$, the converged region density $\overline{n}^{n}_{r,k,i}$ can be obtained as

$$\overline{n}^{n}_{r,k,i} = \frac{\overline{n}^{n(q)}_{r,k,i} - \overline{n}^{n(q-1)}_{r,k,i} w_{k,i,1}}{1 - w_{k,i,1}} - \frac{a_{k,i,2}(w_{k,i,2} - w_{k,i,1}) w^{q-1}_{k,i,2}}{1 - w_{k,i,1}} - \frac{a_{k,i,3}(w_{k,i,3} - w_{k,i,1}) w^{q-1}_{k,i,3}}{1 - w_{k,i,1}} - \cdots . \tag{4.73}$$

If $w_{k,i,2} << w_{k,i,1}$, Eq. (4.71) is reduced to

$$\overline{n}^{n}_{r,k,i} = \frac{\overline{n}^{n(q)}_{r,k,i} - \overline{n}^{n(q-1)}_{r,k,i} w_{k,i,1}}{1 - w_{k,i,1}} . \tag{4.74}$$

This converged region density $\overline{n}^{n}_{r,k,i}$ is calculated by approximating the extrapolation factor $w_{k,i,1}$ in Eq. (4.74), which can be solved for $w_{k,i,1}$ as

$$w_{k,i,1} = \frac{\overline{n}^{n(q)}_{r,k,i} - \overline{n}^{n}_{r,k,i}}{\overline{n}^{n(q-1)}_{r,k,i} - \overline{n}^{n}_{r,k,i}} . \tag{4.75}$$

The elements of the transmutation matrix $\mathbf{B}^{n(q)}_{k}$ over the current subinterval n are used to obtain

$$w_{k,i,1} = \frac{\sum_{j=1}^{I} B^{n(q)}_{k}(i,j)\overline{n}^{n-1(q)}_{r,k,j} - \sum_{j=1}^{I} B^{n}_{k}(i,j)\overline{n}^{n-1(q)}_{r,k,j}}{\sum_{j=1}^{I} B^{n(q-1)}_{k}(i,j)\overline{n}^{n-1(q)}_{r,k,j} - \sum_{j=1}^{I} B^{n}_{k}(i,j)\overline{n}^{n-1(q)}_{r,k,j}} \approx \frac{B^{n(q)}_{k}(i,i) - B^{n(q-1)}_{k}(i,i)}{B^{n(q-1)}_{k}(i,i) - B^{n(q-2)}_{k}(i,i)} . \tag{4.76}$$

where $B^{n(q)}_{k}(i,j)$ represents the (i,j) element of the transmutation matrix $\mathbf{B}^{n(q)}_{k}$. For those isotopes for which $w_{k,i,1}$ is zero, the extrapolation factor is taken as the average of the remaining non-zero extrapolation factors which have already been computed. The extrapolated region density $\overline{n}^{n}_{r,k,i}$ in Eq. (4.74) is then calculated using the extrapolation factor. The extrapolated region density vectors $\mathbf{n}^{n}_{r,k}$ are used in the neutronics solution at time node t_n.

It has been observed that for some problems, in particular thermal reactor problems with burnup-dependent cross sections, the extrapolation procedure leads to erroneous values for the region densities. Thus the region density extrapolation can be deactivated with proper input to card type 02 of A.BURN.

Region Density Extrapolation for Cyclic Mode Iteration

As stated, region density extrapolation is used to accelerate convergence of the region density vectors in order to obtain a converged transmutation matrix over a given subinterval. The objective of the cyclic mode iteration is to achieve a converged transmutation operator $\mathbf{B}_{l,\tau}(T, \overline{\mathbf{n}}_{r,0})$ over the total burn cycle time T. The cyclic mode iterations are considered converged when the inequality in Eq. (4.38) is satisfied.

The region density extrapolation is also used to accelerate convergence of the cyclic mode iterations when $q = 4$, 7, or 10. The extrapolation is performed on the region density vectors as outlined in Eq. (4.74) above. The extrapolation factor $w_{k,i,1}$ is computed with elements of the total $\mathbf{B}_k$ matrix over the total burn cycle time T, rather than the $\mathbf{B}_k^n$ matrix over a single subinterval.

4.3.3. Initial Flux Guesses

For diffusion theory calculations, between 70-80% of the calculation time is spent in obtaining the required neutronics solutions. For transport, this has been observed to be >> 95%. Hence any techniques employed to accelerate the convergence of the neutronics solution will directly affect the total problem calculation time. As an example, the user may provide an initial flux guess and thus reduce the computational effort involved in the first neutronics calculation. Similarly, REBUS uses the flux solution computed at the end of each time step as the initial guess for that step for the next pass through the equilibrium cycle. Due to the different solution strategies for equilibrium problems, two different approaches are used to store the flux solution.

Equilibrium Problems

A maximum of four subintervals may be specified for an equilibrium problem. Hence there are a total of five time nodes at which fluxes will be computed. The REBUS code uses a total of six data sets to save these fluxes. These are referred to as DSRN1 through DSRN6. The BOC and EOC fluxes are always stored on DSRN1 and DSRN2, respectively. If there are subintervals, the intermediate time nodes are stored sequentially on DSRN3 through DSRN5. In each case, the flux for the appropriate time node is used as the initial guess for the neutronics module. The converged flux solution is then stored to that file overwriting the previous flux solution.

In the preliminary search procedure, no subintervals are used and hence DSRN3 through DSRN5 are not used. Due to the poorly converged solutions being obtained at this level, experience has shown that the EOC flux computed after one region density iteration is sufficiently different in shape from that obtained on the first region-density iteration that it is worthwhile to save the second EOC flux on DSRN6. Hence during the preliminary search procedure, each time the first EOC flux is computed, the initial guess is read from DSRN2 and the first converged flux is written on DSRN2 while the second EOC flux guess is obtained for DSRN6.

During the intermediate and final search levels DSRN6 is no longer used in this manner. Instead, it is used to save the flux computed at αT whenever an un-poisoned multiplication factor calculation is made to determine $k(\alpha T)$.

Non-equilibrium Problems

Since an arbitrary number of subintervals may be used in non-equilibrium problems, two different approaches are possible. If the number of subintervals is less than five, then the flux at

each time node is saved on DSRN1 through DSRN5. On the other hand, if the number of subintervals exceeds four then the BOC and EOC flux are saved on DSRN1 and DSRN2. The fluxes from the remaining time nodes are placed on DSRN3. Hence the converged flux from time node t_n is used as the initial guess for the neutronics solution at t_{n+1}.

5. Output Edits

The solution methods used for non-equilibrium and equilibrium problems were described in detail in Chapter 4. In Section 4.3.1, it was noted that the solution procedure had a preliminary search level, an intermediate search level, and a final search level. After the problem has converged at the Final Search level, i.e., the parameters have been determined which satisfy the user supplied constraints, the code repeats the burn cycle using the final converged parameters and begins what is termed the "Final Pass with Full Edits" or simply Final Pass.

During the Final Pass calculation from BOC to EOC, the complete edits described in this section are generated. The start of the Final Pass is indicated by the title "Final Pass with Full Edits." Prior to the Final Pass, REBUS is setup to produce minimal output in the preliminary, intermediate, and final search levels. The user can override this behavior with control options in A.STP027, but REBUS will not produce any cumulative edit (burnup, fluence, etc.) detail until the Final Pass calculation. For the Final Pass, a complete printout from DIF3D and many REBUS specific edits can be provided at each time node t_n. For REBUS, there are many keyword area edits (an area is a set of geometric regions) that are included in specific reactor summary details. To be used properly, the user must consistently define the area with the intended use in those REBUS tables (areas are defined with card type 07 of A.NIP3; Appendix C) or set them up manually using card type 29 of A.BURN. If not setup properly, those specific tables of REBUS output should be ignored by the user noting that REBUS will still produce accurate summary edits of arbitrarily named areas for many other quantities of interest.

The first output in this section is, if applicable, the fuel fabrication details needed to construct the BOC state of the reactor with optional atom density details. Following this is the detailed time node based output starting with BOC. As discussed previously, the TWODANT option uses the output routines of DIF3D and thus the output of TWODANT is not included in the REBUS output stream. For each time step, the output starts with DIF3D which provides a summary of the iterative convergence and, depending upon user input to A.DIF3D (card type 04), the neutron balance tables, power and flux tables by area, region, or mesh, and SUMMAR output [9].

The SUMMAR output from DIF3D is one of the typical selections by most REBUS users. SUMMAR provides a summary of power, flux, and neutron balance for each region and area. In addition, it provides isotope-wise microscopic and macroscopic reaction rates along with the effective one-group microscopic cross sections. More discussion on the SUMMAR output is given later in Section 5.4.

After the BOC neutronics calculation is complete, the remaining subintervals of the fuel cycle time have a repetitive behavior. Note that because REBUS is still performing region density iterations, the DIF3D output section for a given time point can be repeated in the output stream and convergence details on the active isotopes is given. The following REBUS fuel cycle analysis output can be printed after the DIF3D output detail is given for the end of each subinterval:

1) Atom densities (in atoms/barn-cm) of active isotopes

a. Atom densities by stage and path
b. Atomic mass by stage and path
c. Fissile and fissionable isotope mass by stage and path

2) Integrated Conversion ratio
   a. Conversion ratio by region
   b. Conversion and breeding ratios by area
   c. Convergence ratio of each stage of each path
3) User-defined Integrated conversion ratio (card type 46 of A.BURN)
   a. Conversion ratio by region
   b. Conversion and breeding ratios by area
   c. Convergence ratio of each stage of each path
4) Masses of isotopes included in the depletion chain
   a. Masses (in kg) of each isotope in each stage of each path
   b. Total reactor loading (in kg) of each isotope
   c. Reactor loadings (in kg) by area over the subinterval
5) Fissile mass (card type 24 of A.BURN)
   a. Fissile mass of each stage of each path
   b. Fissile mass of each path
   c. Fissile mass of each area
6) Average burnup over the preceding subinterval (No output is possible at BOC)
   a. Average burnup (atom %) of each stage of each path
   b. Average burnup (MWD/MT) of each stage of each path
7) Power
   a. Average daily fission power in MW & Average power of each stage of each path
   b. Instantaneous total power in MW & Total power of each stage of each path
   c. Instantaneous total power/average power
8) Peak burnups (MWD/MT) and peak fast fluence (n/cm^2) over the preceding subinterval
   a. Peak burnup (MWD/MT) of each stage of each path
   b. Peak fast fluence (n/cm^2) of each stage of each path

9) Reactor summary edits
    a. Mass balance (kg)
    b. British definition breeding gain
    c. Neutron balance

Some of the preceding output is not repeated and is only given once when the region density iteration is complete. After all time nodes are completed, REBUS generates the "Cumulative Edits" detail. The cumulative output consists of the following:

1) Cumulative burnup after n subintervals from $n=0$ to N
    a. Average burnup (atom %) of each stage of each path
    b. Average burnup (MWD/MT) of each stage of each path
    c. Burnup summary by area (up to $n=N-1$)
2) Cumulative peak discharge burnup and peak discharge fast fluence ($n=N$)
    a. Peak discharge burnup (MWD/MT) of each path
    b. Peak discharge fast fluence (n/cm^2) of each path
    c. Burnup summary by area

After the cumulative output is generated, a separate output of the burnup constraint which details the burnup assessment of the user-specified test groups and/or path labels. Following that is the external cycle edit that summarizes the mass flow through the external cycle of the user-specified model. If applicable, this is followed by the DIF3D output for the un-poisoned multiplication factor at the chosen time point. If the targeted un-poisoned multiplication factor is achieved, the "Final Search" procedure is completed and the converged enrichment search parameter x and cycle length T are printed. It is noted that in the REBUS output, the enrichment search parameter is printed as "enrichment modification factor" and the cycle length is printed as "burn step time." Finally, the summary edits on reactor characteristics, mass balance, and mass flow are provided.

Each of these outputs are discussed in detail in the following sections for an equilibrium type problem. The non-equilibrium case is similar and any differences are noted.

5.1. Stage Densities and Active Isotope and Fissile Masses

As outlined above, REBUS can output the atom densities of active isotopes in each stage of each path (i.e., material) and the masses of active and fissile isotopes. Different mass edits are provided including those by stage, by path or material, and by area. These edit quantities are defined in this section.

5.1.1. Stage Densities

The stage densities at each time node t_n are calculated using the converged transmutation matrix and the stage densities at the preceding time node t_{n-1} as

$$\mathbf{n}_{l,\tau}^{n} = \mathbf{B}_{k}^{n}\mathbf{n}_{l,\tau}^{n-1}, \quad l = 1,2,\cdots,L;\ \tau = 1,2,\cdots,S(l);\ n = 1,2,\cdots,N, \tag{5.1}$$

where the transmutation matrix is calculated with the region-averaged flux in the region R_k where the stage τ of material l is contained as

$$\mathbf{B}_{l,\tau}^{n} = \exp[\bar{\mathbf{A}}_{l,\tau}^{n}(t_n - t_{n-1})], \tag{5.2}$$

$$\bar{\mathbf{A}}_{l,\tau}^{n} = \frac{1}{2}[\mathbf{A}_{l,\tau}^{n-1}(\bar{\phi}_k^{n-1}) + \mathbf{A}_{l,\tau}^{n}(\bar{\phi}_k^{n})], \quad (l,\tau) \in R_k. \tag{5.3}$$

In REBUS, all of the atom densities are internally represented in units of atoms/barn-cm, i.e., 10^{-24} atoms/cm^3.

Figures 5.1 and 5.2 show an output excerpt of the "atom densities of active isotopes in each stage of each path" edit. Fig. 5.1 is an example for a 3-batch scattered reloading scheme without fuel shuffling, and Fig. 5.2 is an example for a 3-batch reloading scheme with shuffling. In both examples, for each path defined with card type 11 of A.BURN, the stage densities are printed along with the region name included in the path. In the scattered reloading problem in Fig. 5.1, all three stages of the fuel in PATH2 stay in the same region C31B. In this case, the fuel from stages 1 to 3 coexist in the region C31B each with a volume fraction of 1/3 as discussed in Section 2.1.2. They are all depleted using the same region-averaged flux of C31B on a given time interval.

```
    ATOM DENSITIES (IN ATOMS/BARN-CM.) OF ACTIVE ISOTOPES IN EACH STAGE OF EACH PATH

                                                    PATH PATH2

 STAGE REGION
+                 U-234       U-235       U-236       U-238       PU238       NP237 ...
                   PU242       AM241       AM242M      AM243       CM242       CM243 ...
                   FPU5        FPU8        FPPU9       FPPU0       FPPU1       REU5  ...
                   REPU1       DUMP

   1   C31B      4.4118E-07  2.0293E-09  1.7626E-10  6.9127E-03  2.8207E-05  1.3799E-04 ...
                 1.0225E-04  9.6113E-05  6.1081E-07  6.4082E-05  5.1077E-07  1.8835E-07 ...
                 1.9220E-09  6.6896E-06  3.2708E-05  3.6390E-06  1.0898E-05  5.1090E-10 ...
                 2.4575E-06  7.0427E-10
   2   C31B      7.2791E-07  5.8303E-09  3.6521E-10  6.8815E-03  3.0561E-05  1.3483E-04 ...
                 1.0291E-04  1.1101E-04  9.7494E-07  6.3321E-05  6.6791E-07  1.7683E-07 ...
                 5.6341E-09  1.3372E-05  6.4908E-05  7.2716E-06  2.1080E-05  1.4977E-09 ...
                 4.7534E-06  1.4103E-09
   3   C31B      1.0345E-06  1.1473E-08  5.7812E-10  6.8505E-03  3.3006E-05  1.3174E-04 ...
                 1.0348E-04  1.2401E-04  1.3727E-06  6.2579E-05  7.6636E-07  1.6636E-07 ...
                 1.1295E-08  2.0052E-05  9.6616E-05  1.0897E-05  3.0614E-05  3.0024E-09 ...
                 6.9032E-06  2.1189E-09
```

Fig. 5.1. Example Output of Stage Densities for Scattered Reloading without Shuffling

```
    ATOM DENSITIES (IN ATOMS/BARN-CM.) OF ACTIVE ISOTOPES IN EACH STAGE OF EACH PATH

                                                        PATH PATH2

 STAGE REGION
+                 U-234       U-235       U-236       U-238       PU238       NP237 ...
                   PU242       AM241       AM242M      AM243       CM242       CM243 ...
                   FPU5        FPU8        FPPU9       FPPU0       FPPU1       REU5  ...
                   REPU1       DUMP

   1   C21B      4.3916E-07  2.8911E-09  3.0836E-10  6.9138E-03  2.8727E-05  1.3567E-04 ...
                 1.0173E-04  9.4244E-05  7.2807E-07  6.3273E-05  7.0830E-07  1.8423E-07 ...
                 3.2204E-09  1.1670E-05  4.9110E-05  6.0534E-06  1.6255E-05  8.5606E-10 ...
                 3.6653E-06  1.0970E-09
   2   C31B      7.3193E-07  6.6805E-09  4.9728E-10  6.8826E-03  3.1185E-05  1.3255E-04 ...
                 1.0237E-04  1.0881E-04  1.0793E-06  6.2525E-05  6.8527E-07  1.7317E-07 ...
                 6.9438E-09  1.8306E-05  8.0841E-05  9.6367E-06  2.6246E-05  1.8458E-09 ...
                 5.9182E-06  1.7970E-09
   3   C32B      1.0433E-06  1.3093E-08  7.5330E-10  6.8471E-03  3.3784E-05  1.2910E-04 ...
                 1.0292E-04  1.2105E-04  1.5082E-06  6.1682E-05  8.3785E-07  1.6234E-07 ...
                 1.3763E-08  2.6341E-05  1.1684E-04  1.3910E-05  3.7018E-05  3.6585E-09 ...
                 8.3472E-06  2.6141E-09
```

Fig. 5.2. Example Output of Stage Densities for Reloading Scheme with Shuffling

In Fig. 5.2, the fuel assigned to PATH2 is initially loaded in region C21B and then moved to C31B and then to C32B for the two follow-on burn cycles. For a given time node, a region contains only a single stage of the fuel and thus the volume fraction is 1.0 for all three stages. Unlike the batch fuel case of Fig. 5.1, the fuel in this case is depleted using the region-averaged flux of the associated region.

It should be noted that in the scattered loading scheme, a fuel management path is defined using a single zone while the shuffling scheme is defined by a sequence of regions where the fuel is located. For a scattered loading scheme, if a zone is assigned to multiple regions with card type 15 of A.NIP3, the zone is duplicated to the regions it is assigned to. For example, consider a zone PCM1 assigned to the regions REG1, REG2, and REG3. If a 3-batch fuel management path PATH2 is defined by assigning PCM1 to the three regions by stage, then REBUS will report the presence of three PATH2 paths associated with one assigned to each region. Therefore, the stage density output in Fig. 5.1 is provided for all three PATH2 cases and the three regions originally assigned to that path.

To estimate the average fission power and the integrated conversion ratios over a subinterval (t_{n-1},t_n), the average nuclide density vector over this subinterval is calculated using Eq. (4.14) as

$$\bar{\mathbf{n}}_{l,\tau}^{n} = \frac{1}{\Delta t_n}\int_{t_{n-1}}^{t_n} \mathbf{n}_{l,\tau}(t)dt = \mathbf{F}_{l,\tau}^{n}\mathbf{n}_{l,\tau}^{n-1}, \tag{5.4}$$

where $\mathbf{F}_{l,\tau}^{n}$ is the average of the transmutation rate matrix $\mathbf{B}_{l,\tau}^{n} = e^{\bar{\mathbf{A}}_{l,\tau}^{n}\Delta t_n}$ over a subinterval (t_{n-1},t_n) given in Eq. (4.15) as

$$\mathbf{F}_{l,\tau}^{n} = F(\bar{\mathbf{A}}_{l,\tau}^{n}\Delta t_n) = \frac{1}{\Delta t_n}\int_{t_{n-1}}^{t_n} e^{\bar{\mathbf{A}}_{l,\tau}^{n} t}\,dt = (\bar{\mathbf{A}}_{l,\tau}^{n}\Delta t_n)^{-1}(e^{\bar{\mathbf{A}}_{l,\tau}^{n}\Delta t_n} - \mathbf{I})\,. \tag{5.5}$$

This average transmutation matrix can be calculated as a byproduct of the transmutation matrix $\mathbf{B}_{l,\tau}^{n}$ as discussed in Section 4.1.2.

5.1.2. Active Isotope Mass

Using the stage densities in Eq. (5.1), the mass of each active isotope in stage τ of material l at a time node t_n is computed using

$$M_{l,\tau,i}^{n} = \frac{n_{l,1,i}^{n} A_i v_{l,\tau} V_k}{N_A} \times \frac{10^{-24}}{10^{3}} \quad (\text{kg})\,, \tag{5.6}$$

where N_A is Avogadro's number, A_i is the atomic weight of isotope i, $v_{l,\tau}$ is the volume fraction of stage τ of material l in region R_k in which it is contained, and V_k is the volume of region R_k. As discussed above, $v_{l,\tau} = 1/S(l)$ for a scattered reloading scheme and $v_{l,\tau} = 1$ for a reloading scheme with shuffling. The constant 10^{-24} is used to convert the nuclide density unit from atoms/barn·cm to atoms/cm^3 and the constant 10^3 is used to convert the mass unit from gram to kg.

Figures 5.3 and 5.4 show an output excerpt for the "masses of active isotopes in each stage of each path." Fig. 5.3 is an example for the 3-batch scattered reloading scheme without fuel shuffling, and Fig. 5.4 is an example for the 3-batch reloading scheme with shuffling. As was

```
           MASSES (IN KG) OF ACTIVE ISOTOPES IN EACH STAGE OF EACH PATH

           PATH PATH2      TOTAL MASS OF FISSIONABLE ISOTOPES IN STAGE 1 =  2.86319E+01
STAGE REGION
                 U-234       U-235       U-236       U-238       PU238       NP237 ...
                 PU242       AM241       AM242M      AM243       CM242       CM243 ...
                 FPU5        FPU8        FPPU9       FPPU0       FPPU1       REU5  ...
                 REPU1       DUMP

  1   C21B    1.2989E-03  8.5309E-06  9.0417E-07  2.0620E+01  8.6387E-02  4.0650E-01 ...
              3.1119E-01  2.8719E-01  2.2198E-03  1.9439E-01  2.1542E-03  5.6612E-04 ...
              9.4472E-06  3.4343E-02  1.4708E-01  1.8137E-02  4.9114E-02  2.5113E-06 ...
              1.1075E-02  3.3581E-06
  2   C21B    2.1593E-03  2.4472E-05  1.8744E-06  2.0483E+01  9.5714E-02  3.9308E-01 ...
              3.1334E-01  3.2735E-01  3.6865E-03  1.9091E-01  2.7843E-03  5.2525E-04 ...
              2.7854E-05  6.8589E-02  2.9058E-01  3.6176E-02  9.4555E-02  7.4042E-06 ...
              2.1321E-02  6.7130E-06
  3   C21B    3.0923E-03  4.8152E-05  2.9771E-06  2.0346E+01  1.0513E-01  3.8013E-01 ...
              3.1497E-01  3.6085E-01  5.2346E-03  1.8756E-01  3.1537E-03  4.8932E-04 ...
              5.6202E-05  1.0276E-01  4.3066E-01  5.4112E-02  1.3672E-01  1.4940E-05 ...
              3.0830E-02  1.0071E-05
```

Fig. 5.3. Example Output of Stage Masses for Scattered Reloading without Shuffling

```
          MASSES (IN KG) OF ACTIVE ISOTOPES IN EACH STAGE OF EACH PATH

             PATH PATH2      TOTAL MASS OF FISSIONABLE ISOTOPES IN STAGE 1 =  8.58958E+01
STAGE REGION
                 U-234       U-235       U-236       U-238       PU238       NP237 ...
                 PU242       AM241       AM242M      AM243       CM242       CM243 ...
                 FPU5        FPU8        FPPU9       FPPU0       FPPU1       REU5  ...
                 REPU1       DUMP

  1   C21B    3.8721E-03  2.5601E-05  2.7421E-06  6.2004E+01  2.5763E-01  1.2116E+00 ...
              9.2766E-01  8.5587E-01  6.6393E-03  5.7938E-01  6.4589E-03  1.6870E-03 ...
              2.8516E-05  1.0466E-01  4.4228E-01  5.4744E-02  1.4766E-01  7.5803E-06 ...
              3.3296E-02  1.0128E-05
  2   C31B    6.4534E-03  5.9154E-05  4.4221E-06  6.1724E+01  2.7967E-01  1.1837E+00 ...
              9.3348E-01  9.8815E-01  9.8424E-03  5.7254E-01  6.2489E-03  1.5857E-03 ...
              6.1486E-05  1.6417E-01  7.2804E-01  8.7151E-02  2.3842E-01  1.6344E-05 ...
              5.3762E-02  1.6590E-05
  3   C32B    9.1987E-03  1.1594E-04  6.6988E-06  6.1405E+01  3.0298E-01  1.1529E+00 ...
              9.3858E-01  1.0993E+00  1.3753E-02  5.6482E-01  7.6404E-03  1.4866E-03 ...
              1.2187E-04  2.3623E-01  1.0522E+00  1.2580E-01  3.3628E-01  3.2395E-05 ...
              7.5828E-02  2.4135E-05
```

Fig. 5.4. Example Output of Stage Masses for Reloading Scheme with Shuffling

the case for the preceding stage density output, the stage masses are printed according to the region where the fuel is located. The initial mass of fissionable isotopes is provided earlier in the output stream for each fuel management path. This initial mass of fissionable isotopes is used in calculating the burnup in the unit of MWD/MT as discussed below.

The mass of an active isotope i in a region R_k are obtained by summing up the stage masses

$$M^n_{r,k,i} = \sum_{(l,\tau)\in R_k} M^n_{l,\tau,i} \,. \tag{5.7}$$

For a scattered reloading without shuffling, the mass of an active isotope i in a region R_k is obtained using

$$M^n_{r,k,i} = \sum_{\tau=1}^{S(l)} M^n_{l,\tau,i}, \quad l \in R_k \,. \tag{5.8}$$

In a fuel management scheme with shuffling, a region contains only one stage of fuel and thus the mass of active isotope i in region R_k is obtained using

$$M^n_{r,k,i} = M^n_{l,\tau,i}, \quad (l,\tau) \in R_k \,. \tag{5.9}$$

The mass of isotope i in area A is obtained by summing the masses in the regions belonging to the area A

$$M^n_{A,i} = \sum_{k\in A} M^n_{r,k,i} \,. \tag{5.10}$$

Similarly, the total reactor loading of active isotope i is obtained by summing over all regions

$$M_{Rx,i}^{n} = \sum_{k=1}^{K} M_{r,k,i}^{n} , \tag{5.11}$$

where Rx denotes the entire reactor composed of K regions. Fig. 5.5 shows an example output for the total reactor loading of active isotopes at a given time node.

```
TOTAL REACTOR LOADING (IN KG) OF ACTIVE ISOTOPES AT TIME NODE  1 AT  4.65000E+02 DAYS.

                        ISOTOPE  REACTOR LOADING

                        U-234       2.06150E-02
                        U-235       2.15841E-04
                        U-236       1.49780E-05
                        U-238       6.03395E+02
                        PU238       8.88831E-01
                        NP237       3.74840E+00
                        PU239       3.78333E+01
                        PU240       1.47129E+01
                        PU241       7.90295E+00
                        PU242       2.95543E+00
                        AM241       3.10297E+00
                        AM242M      3.22261E-02
                        AM243       1.81114E+00
                        CM242       2.18412E-02
                        CM243       5.01847E-03
                        CM244       4.06581E-01
                        CM245       4.36416E-02
                        CM246       5.07269E-03
                          .
                          .
```

Fig. 5.5. Example Output of Total Reactor Loading

5.1.3. *Fissile and Fissionable Masses*

The fissile and fissionable isotope masses, which are used in the conversion ratio and burnup calculations, are calculated by summing the active isotope masses over the user defined subsets. Each active isotope can be designated as fissile or fertile by proper input on card type 24 of A.BURN and the fissionable isotopes are identified by REBUS based upon the presence of a fission reaction on card type 09 of A.BURN.

The fissile mass in stage τ of material l is determined by adding the masses of the fissile isotopes using

$$M_{l,\tau}^{n,fissile} = \sum_{i \in fissile} M_{l,\tau,i}^{n} . \tag{5.12}$$

Similarly, the initial mass of fissionable atoms is calculated by adding the masses of fissionable isotopes in stage 1

$$M_{l,0}^{fissionable} = \sum_{i \in fissioable} M_{l,1,i}^{0} . \tag{5.13}$$

This is the initial mass of fissionable isotopes for each fuel management path in Figs. 5.3 and 5.4.

For the fissile mass edit by path, the fissile mass of a path is calculated by summing the fissile masses of the stages in a path

$$M_l^{n,fissile} = \sum_{\tau=1}^{S(l)} M_{l,\tau}^{n,fissile} . \tag{5.14}$$

The masses of fissile and fissionable isotopes in region R_k are calculated in a similar way to the active isotopes in Eq. (5.7) with

$$M_{r,k}^{n,fissile} = \sum_{(l,\tau)\in R_k} M_{l,\tau}^{n,fissile} \text{ and} \tag{5.15}$$

$$M_{r,k,0}^{fissionable} = \sum_{(l,1)\in R_k} M_{l,0}^{fissionable} . \tag{5.16}$$

The masses of fissile and fissionable isotopes in area A are also obtained by summing the masses in the regions belonging to that area with

$$M_A^{n,fissile} = \sum_{k\in A} M_{r,k}^{n,fissile} , \tag{5.17}$$

$$M_{A,0}^{fissionable} = \sum_{k\in A} M_{r,k,0}^{fissionable} , \tag{5.18}$$

Similarly, the total reactor loading of fissile and fissionable isotopes are obtained using

$$M_{Rx}^{n,fissile} = \sum_{k\in Rx} M_{r,k}^{n,fissile} , \tag{5.19}$$

$$M_{Rx,0}^{fissionable} = \sum_{k\in Rx} M_{r,k,0}^{fissionable} , \tag{5.20}$$

Figures 5.6 and 5.7 show example fissile mass outputs for the scattered reloading scheme without shuffling and the reloading scheme with shuffling, respectively. Three fuel management

```
                    FISSILE MASS OF EACH STAGE OF EACH PATH

STAGE/REGION  1/C11B      2/C11B      3/C11B
              7.98068E-01  7.64383E-01  7.33475E-01
STAGE/REGION  1/C21B      2/C21B      3/C21B
              4.80730E+00  4.62155E+00  4.45027E+00
STAGE/REGION  1/C31B      2/C31B      3/C31B
              4.85713E+00  4.71566E+00  4.58374E+00
STAGE/REGION  1/C32B      2/C32B      3/C32B
              4.84214E+00  4.68721E+00  4.54319E+00
STAGE/REGION  1/B41B      2/B41B      3/B41B
              8.40016E-02  1.66555E-01  2.47683E-01
STAGE/REGION  1/B42B      2/B42B      3/B42B
              1.09353E-01  2.16131E-01  3.20392E-01
STAGE/REGION  1/B43B      2/B43B      3/B43B
              1.09353E-01  2.16131E-01  3.20392E-01

                         FISSILE MASS OF EACH PATH

PATH          PATH1        PATH2        PATH2        PATH2        PATH3        PATH3    ...
         2.29592E+00  1.38791E+01  1.41565E+01  1.40725E+01  4.98239E-01  6.45876E-01 ...
```

Fig. 5.6. Example Output of Fissile Masses for Scattered Reloading without Shuffling

```
                  FISSILE MASS OF EACH STAGE OF EACH PATH

STAGE/REGION  1/C11B      2/C11B      3/C11B
              7.92880E-01  7.59280E-01  7.28466E-01
STAGE/REGION  1/C21B      2/C31B      3/C32B
              1.43296E+01  1.39172E+01  1.34928E+01
STAGE/REGION  1/B41B      2/B42B      3/B43B
              2.52146E-01  5.74660E-01  8.89418E-01

                  FISSILE MASS OF EACH PATH

PATH          PATH1        PATH2        PATH3
         2.28063E+00  4.17396E+01  1.71622E+00
```

Fig. 5.7. Example Output of Fissile Masses for Reloading Scheme with Shuffling

paths are defined in both problems: PATH1, PATH2, and PATH3. In the example in Fig. 5.6, PATH2 is defined by assigning a zone to regions C21B, C31B, and C32B, and PATH3 is defined by assigning a zone to regions B41B, B42B, and B43B. As mentioned above, PATH2 and PATH3 are duplicated three times. The three fissile masses for PATH2 are the masses in the regions C21B, C31B, and C32B which corresponds to the ordering of the path input. In contrast is Fig. 5.7 where PATH2 is defined with a sequence of fuel movements which leads to a single fissile mass output at a time node.

5.2. Conversion and Breeding Ratios

REBUS calculates the "instantaneous" conversion ratio of fissile nuclides at BOC and the "integrated" conversion ratio at all other time nodes. It also calculates the conversion ratio for regions and areas and the breeding ratio for areas.

5.2.1. Instantaneous Conversion Ratio

The instantaneous conversion ratio for each stage τ of each material l is calculated using the flux and stage densities at BOC as

$$\mathrm{CR}_{l,\tau}^{\text{instant}} = \frac{\text{Fissile atom production rate in } (l,\tau)}{\text{Fissile atom destruction rate in } (l,\tau)} = \frac{\mathrm{FP}_{l,\tau}^{0}}{\mathrm{FD}_{l,\tau}^{0}}, \tag{5.21}$$

where the fissile production to destruction rates at time zero given by

$$\mathrm{FP}_{l,\tau}^{0} = \sum_{i \in fissile} \sum_{j=1, j\neq i}^{I} A_{l,\tau}^{0}(i,j) n_{l,\tau,j}^{0}, \tag{5.22}$$

$$\mathrm{FD}_{l,\tau}^{0} = -\sum_{i \in fissile} A_{l,\tau}^{0}(i,i) n_{l,\tau,i}^{0}. \tag{5.23}$$

$A_{l,\tau}^{n}(i,j)$ is the (i,j) element of the transmutation rate matrix $\mathbf{A}_{l,\tau}^{n}$ of stage τ of material type l at time node t_n. $n_{l,\tau,i}^{n}$ is the atom density of isotope i in stage τ of material l at time node t_n.

5.2.2. Integrated Conversion Ratio

The integrated conversion ratio is determined using the neutron flux and nuclide densities averaged over a subinterval with

$$\mathrm{CR}_{l,\tau}^{n} = \frac{\text{Fissile atoms produced in } (l,\tau) \text{ over subinterval } n}{\text{Fissile atoms destroyed in } (l,\tau) \text{ over subinterval } n} = \frac{\mathrm{FP}_{l,\tau}^{n}}{\mathrm{FD}_{l,\tau}^{n}}. \tag{5.24}$$

The number of fissile atoms produced and destroyed over the subinterval t_n are calculated using

$$\mathrm{FP}_{l,\tau}^{n} = \sum_{i\in fissile}\sum_{j=1,j\neq i}^{I} \bar{A}_{l,\tau}^{n}(i,j)\bar{n}_{l,\tau,j}^{n}\Delta t_n = \sum_{m=1}^{I}\left[\sum_{i\in fissile}\sum_{j=1,j\neq i}^{I} \bar{A}_{l,\tau}^{n}(i,j)F_{l,\tau}^{n}(j,m)\right] n_{l,\tau,m}^{n-1}\Delta t_n \text{ and} \tag{5.25}$$

$$\mathrm{FD}_{l,\tau}^{n} = -\sum_{i\in fissile} \bar{A}_{l,\tau}^{n}(i,i)\bar{n}_{l,\tau,i}^{n}\Delta t_n = -\sum_{m=1}^{I}\left[\sum_{i\in fissile} \bar{A}_{l,\tau}^{n}(i,i)F_{l,\tau}^{n}(i,m)\right] n_{l,\tau,m}^{n-1}\Delta t_n . \tag{5.26}$$

$\bar{A}_{l,\tau}^{n}(i,j)$ is the (i,j) element of the average transmutation rate matrix $\bar{\mathbf{A}}_{l,\tau}^{n}$ over subinterval (t_{n-1},t_n) from Eq. (5.3). $\bar{n}_{l,\tau,i}^{n}$ is the i-th element of the average stage density vector over subinterval (t_{n-1},t_n) from Eq. (5.4). $F_{l,\tau}^{n}(i,j)$ is the (i,j) element of $\mathbf{F}_{l,\tau}^{n}$ from Eq. (5.5), which is the average of the transmutation matrix $\mathbf{B}_{l,\tau}^{n}$ over a subinterval (t_{n-1},t_n), and $\Delta t_n = t_n - t_{n-1}$ is the length of the subinterval.

The numerator of the conversion ratio should be the net number of fissile atoms produced over a time interval of interest. However, the numerator of the conversion ratio in Eq. (5.25) includes the total number of fissile atoms produced during a time interval, not the net number of atoms produced. Therefore, the fissile atoms that are produced, but later destroyed during the time interval, are included in the numerator. If needed, the user can estimate the net number of fissile atoms produced during a cycle by adding the fissile inventory increment to the fissile atoms destroyed as

$$\mathrm{FP}_{l,\tau}^{\mathrm{net}} = \mathrm{FD}_{l,\tau}^{\mathrm{cycle}} + (\mathrm{F}_{l,\tau}^{\mathrm{EOC}} - \mathrm{F}_{l,\tau}^{\mathrm{BOC}}), \tag{5.27}$$

where $\mathrm{FP}_{l,\tau}^{\mathrm{net}}$ is the net production of fissile atoms during a cycle, and $\mathrm{FD}_{l,\tau}^{\mathrm{cycle}}$ is the fissile destruction rate calculated with Eq. (5.26) over the cycle. The fissile inventories $\mathrm{F}_{l,\tau}^{\mathrm{BOC}}$ and $\mathrm{F}_{l,\tau}^{\mathrm{EOC}}$ at BOC and EOC can be obtained from the isotopic inventory output of REBUS.

It should be noted that the fissile isotopes included in the fissile conversion or breeding ratio are specified via card type 24 of A.BURN. However, if the fissile isotopes are defined such that one isotope is produced by a reaction of another isotope, the calculated conversion ratio is not correct since the transmutation among the fissile isotopes is included in the production and destruction rates of that fissile isotope. For example, the conversion ratio of transuranic (TRU) isotopes cannot be determined by specifying them as fissile isotopes using just card type 24. The

TRU or minor actinide (MA) conversion ratios can be calculated via the user-defined conversion ratio specified with card type 46 of A.BURN which are described later in this chapter.

5.2.3. Region and Area Conversion Ratios

The conversion ratio for a region or area is obtained by integrating the numerator and the denominator over the region or area of interest. That is, it is the ratio of the fissile atoms produced in the region (or area) of interest to the fissile atoms destroyed in the region (or area). The number of atoms produced and destroyed in a region R_k is calculated using

$$\mathrm{FP}_k^n = \sum_{(l,\tau)\in R_k} \mathrm{FP}_{l,\tau}^n v_{l,\tau} V_k \,, \tag{5.28}$$

$$\mathrm{FD}_k^n = \sum_{(l,\tau)\in R_k} \mathrm{FD}_{l,\tau}^n v_{l,\tau} V_k \,, \tag{5.29}$$

where $v_{l,\tau}$ is the volume fraction of stage τ of material l in region R_k in which it appears, and V_k is the volume of region R_k. The conversion ratio in region R_k is obtained with

$$\mathrm{CR}_k^n = \frac{\mathrm{FP}_k^n}{\mathrm{FD}_k^n}. \tag{5.30}$$

It is noted that manually summing REBUS region or area conversion ratios will not produce a meaningful conversion ratio.

Figure 5.8 shows an output excerpt of the conversion ratio by region and the conversion and breeding ratios by area. It can be seen that "U-235," "PU239," and "Pu241" were defined as fissile materials. For each region, the fissile atoms produced in Eq. (5.28) and the fissile atoms destroyed in Eq. (5.29) are provided as well as the conversion ratio. These latter quantities can be summed over regions to produce a combined region (or area) conversion ratio.

The areas "CORE" and "BLKT" are composed of the core and blanket regions, respectively. The area "RCTR" is the sum of the two regions. It can be seen that the total conversion ratio over all the regions given by the region label "TOTAL" is equal to the conversion ratio in the area "RCTR," which is composed of all the regions in the reactor. It is also noted that the sum of the two conversion ratios of the areas CORE and BLKT is not equal to the total conversion ratio of the area RCTR and thus it is meaningless as mentioned above.

5.2.4. Area Breeding Ratios

The breeding ratio for an area is given by the ratio of the fissile atoms produced in the area of interest to the fissile atoms destroyed in the entire reactor. The breeding ratio for region A is given by

```
                  INTEGRATED CONVERSION RATIOS BY REGION

    N.B., THE CONVERSION AND BREEDING RATIOS GIVEN IN THE FOLLOWING TABLES
    ARE 'INTEGRATED' VALUES. SPECIFICALLY, THEY ARE COMPUTED FROM THE
    TOTAL FISSILE ATOMS PRODUCED AND DESTROYED OVER THE PRECEDING 465.00
    DAY SUBINTERVAL. THE FISSILE ISOTOPES INCLUDED IN THESE CALCULATIONS
    ARE,
         U-235
         PU239
         PU241

REGION            CONVERSION RATIO  FISSILE ATOMS FORMED  FISSILE ATOMS DESTROYED

 C11B                 3.91699E-01         1.63356E-01            4.17044E-01
 C21B                 3.68638E-01         8.82753E-01            2.39463E+00
                             .
                             .
 TOTAL                7.42333E-01         4.67613E+00            6.29924E+00

                  CONVERSION AND BREEDING RATIOS BY AREA

AREA   CONVERSION RATIO   BREEDING RATIO   FISSILE ATOMS FORMED   FISSILE ATOMS DESTROYED

 CORE    3.80166E-01       3.76210E-01        2.36984E+00            6.23368E+00
 BLKT    3.51787E+01       3.66123E-01        2.30630E+00            6.55594E-02
 RCTR    7.42333E-01       7.42333E-01        4.67613E+00            6.29924E+00
```

Fig. 5.8. Example Output of Conversion Ratios by Region and Conversion and Breeding Ratios by Area

$$\mathrm{BR}_A^n = \frac{\sum_{k\in A} \mathrm{FP}_k^n}{\sum_{k\in Rx} \mathrm{FD}_k^n}, \tag{5.31}$$

where Rx in the denominator denotes a sum over all regions in the entire reactor. The total reactor breeding ratio is given by

$$\mathrm{BR}_{Rx}^n = \frac{\sum_{k\in Rx} \mathrm{FP}_k^n}{\sum_{k\in Rx} \mathrm{FD}_k^n}. \tag{5.32}$$

With this definition, the sum of the area breeding ratios will yield the total reactor breeding ratio.

The area breeding ratios are also shown in the above Fig. 5.8. It can be seen that the sum of the breeding ratios of the areas CORE and BLKT is equal to the breeding ratio of the reactor (RCTR).

5.3. User-defined Conversion Ratios

As mentioned earlier, the conversion ratio for a TRU or MA dominated system cannot be calculated using just the card type 24 of A.BURN specification. The conversion ratio in these cases should be calculated by specifically identifying a set of nuclides to include via card type 46 of A.BURN.

REBUS calculates an integrated conversion ratio for a given nuclide set S by combining the neutron flux and nuclide densities averaged over a subinterval to get

$$\mathrm{CR}_{l,\tau}^{n,S} = \frac{\text{Net number of atoms in set S produced over subinterval}}{\text{Net number of atoms in set S destroyed over subinterval}} = \frac{\mathrm{FP}_{l,\tau}^{n,S}}{\mathrm{FD}_{l,\tau}^{n,S}}. \tag{5.33}$$

The number of atoms in set S produced and that destroyed over the subinterval (t_{n-1}, t_n) are calculated with

$$\mathrm{FP}_{l,\tau}^{n,S} = \sum_{i\in S}\sum_{j\notin S} \bar{A}_{l,\tau}^{n}(i,j)\bar{n}_{l,\tau,j}^{n}\Delta t_n = \sum_{m=1}^{I}\left[\sum_{i\in S}\sum_{j\notin S} \bar{A}_{l,\tau}^{n}(i,j)F_{l,\tau}^{n}(j,m)\right] n_{l,\tau,m}^{n-1}\Delta t_n\,, \tag{5.34}$$

$$\mathrm{FD}_{l,\tau}^{n,S} = \sum_{i\notin S}\sum_{j\in S} \frac{1}{\alpha_{ij}} \bar{A}_{l,\tau}^{n}(i,j)\bar{n}_{l,\tau,j}^{n}\Delta t_n = \sum_{m=1}^{I}\left[\sum_{i\notin S}\sum_{j\in S} \frac{1}{\alpha_{ij}} \bar{A}_{l,\tau}^{n}(i,j)F_{l,\tau}^{n}(j,m)\right] n_{l,\tau,m}^{n-1}\Delta t_n\,. \tag{5.35}$$

The number of atoms produced is calculated by summing the transmutations from the reacting nuclides that are not within the set ($j \notin S$) to the product nuclides that are in the set ($i \in S$). The number of atoms destroyed is calculated by summing the transmutations from the reacting nuclides that are in the set ($j \in S$) to the product nuclides that are not in the set ($i \notin S$) which accounts for the production of multiple products. If the product isotope i is a fission product, α_{ij} is the sum of the fission product yields of the fission reaction of isotope j,

$$\alpha_{ij} = \sum_{m\in FP} \gamma_{jf}^{m}\,, \tag{5.36}$$

where γ_{jf}^{m} is the yield fraction of isotope m from isotope j fission. Otherwise, $\alpha_{ij} = 1$. If multiple products are produced by a non-fission reaction, the sum of the yield fractions specified on card type 09 of A.BURN must be 1.0.

The user-defined conversion ratio for a region or area is calculated in the same way as the fissile conversion ratio described above. For example, the conversion ratio of the isotopes in set S for region R_k is calculated using

$$\mathrm{CR}_{k}^{n,S} = \frac{\mathrm{FP}_{k}^{n,S}}{\mathrm{FD}_{k}^{n,S}}. \tag{5.37}$$

where

$$\mathrm{FP}_{k}^{n,S} = \sum_{(l,\tau)\in R_k} \mathrm{FP}_{l,\tau}^{n,S} v_{l,\tau} V_k \quad \text{and} \tag{5.38}$$

$$\mathrm{FD}_{k}^{n,S} = \sum_{(l,\tau)\in R_k} \mathrm{FD}_{l,\tau}^{n,S} v_{l,\tau} V_k\,. \tag{5.39}$$

Figures 5.9 and 5.10 show output excerpts of two user-defined conversion ratios. The first user-defined set includes U-235 and all transuranic (TRU) isotopes while the second one only consists of minor actinides (MA). The headings “fissile atoms formed” and “fissile atoms

destroyed" mean the atoms produced and destroyed for the given isotope set. Area and total core edits of each conversion ratio are outputted consistent with the previous examples.

```
                User-defined Conversion Ratio 1

 The conversion and breeding ratios in the following tables
 are 'integrated' values. Specifically, they are computed from
 the total atoms produced and destroyed over the preceding
 135.00 day subinterval. The isotopes included in these
 calculations are,
                    U-235
                    NP237
                    PU236
                    PU238
                    PU239
                    PU240
                    PU241
                    PU242
                    AM241
                    AM242
                    AM243
                    CM242
                    CM243
                    CM244
                    CM245
                    CM246

REGION             CONVERSION RATIO  FISSILE ATOMS FORMED  FISSILE ATOMS DESTROYED

  OC01D                 2.81611E-02         3.11162E-02            1.10494E+00
  OC01E                 2.30106E-02         3.28583E-02            1.42796E+00
                              .
```

Fig. 5.9. Example Output of User-Defined Conversion Ratio of TRU and U-235 by Region

```
                User-defined Conversion Ratio 2

 The conversion and breeding ratios in the following tables
 are 'integrated' values. Specifically, they are computed from
 the total atoms produced and destroyed over the preceding
 135.00 day subinterval. The isotopes included in these
 calculations are,
                    NP237
                    AM241
                    AM242
                    AM243
                    CM242
                    CM243
                    CM244
                    CM245
                    CM246

REGION             CONVERSION RATIO  FISSILE ATOMS FORMED  FISSILE ATOMS DESTROYED

 OC01D                 6.93320E-02         6.52997E-02            9.41840E-01
 OC01E                 6.48362E-02         7.16252E-02            1.10471E+00
                              .
```

Fig. 5.10. Example Output of User-Defined MA Conversion Ratios by Region

5.4. Burnup

REBUS calculates two material burnups for each stage of each material. One is in the unit of atom % and the other is in the unit of MWD/MT. Note that the alternative burnup definition for

ESPG < 0 discussed in Section 3.2.2 is used only for the test group burnup calculation. The burnup edits at each time node are calculated based upon the fission loss only.

5.4.1. Atom % Burnup

The burnup in atom % is calculated by the ratio of the number of atoms destroyed over a time interval to the total fissionable atoms initially present in the fuel as

$$\mathrm{Bu}_{l,\tau}^{n,at\%} = \frac{\text{Number of atoms destroyed over a time interval}}{\text{Number of fissionable atoms initially present}} \times 100 = \frac{\mathrm{BN}_{l,\tau}^{n,at}}{\mathrm{BD}_{l,\tau}^{n,at}} \times 100. \qquad (5.40)$$

The numerator is estimated using the time-averaged number of fission products produced over the time interval as

$$\begin{aligned} \mathrm{BN}_{l,\tau}^{n,at} &= \sum_j \left[\sum_{i \in FP} \bar{A}_{l,\tau}^{n}(i,j) \bar{n}_{l,\tau,j}^{n} \Delta t_n V_l \Big/ \sum_{i \in FP} \gamma_{jf}^{i} \right] \\ &= \sum_j \left[\sum_{i \in FP} \bar{A}_{l,\tau}^{n}(i,j) \left\{ \sum_{m=1}^{I} F_{l,\tau}^{n}(j,m) n_{l,\tau,m}^{n-1} \right\} \Delta t_n V_l \Big/ \sum_{i \in FP} \gamma_{jf}^{i} \right]. \end{aligned} \qquad (5.41)$$

where γ_{jf}^{i} is the yield fraction of isotope i from a fission of isotope j. The summation j is taken over the isotopes specified with card type 07 of A.BURN. If no card type 07 is given, j is summed over all fissionable isotopes. The denominator is obtained by the sum of all fissionable atoms in the stage 1 material,

$$\mathrm{BD}_{l,\tau}^{n,at} = \sum_i n_{l,1,i}^{0}. \qquad (5.42)$$

The summation over i is taken over the isotopes specified with card type 08 of A.BURN. If no card type 08 is given, it is taken over all fissionable isotopes.

5.4.2. MWD/MT Burnup

The burnup in MWD/MT is defined by the ratio of the fission energy produced over a time step to the total mass of fissionable atoms initially present in the fuel. The fission energy produced over a time step is calculated by dividing the number of atoms destroyed by fission in Eq. (5.41) by the energy conversion factor $C_{l,\tau}^{fiss/J}$ in fissions per W-s. The factor $C_{l,\tau}^{fiss/J}$ of stage τ of material l is calculated by the HMG4C module during each DIF3D calculation and stored in the COMPXS dataset [9]. For the materials for which the energy conversion factor is not specified, a default value of 3.1×10^{10} fissions/W-s is used. From Eq. (5.41) and Eq. (5.42), the burnup in MWD/MT is calculated using

$$\mathrm{Bu}_{l,\tau}^{n,MWD} = \frac{\mathrm{BN}_{l,\tau}^{n,at} v_{l,1} V_k}{8.64\times10^{7} \times C_{l,\tau}^{fiss/J} M_{l,0}^{fissionable}}, \qquad (5.43)$$

where the constant 8.64×10^{7} is used to convert the unit from W-s/kg to MWD/MT.

Figure 5.11 shows an output excerpt for the average burnup of each stage of each path in atom % and MWD/MT for a problem with scattered loading without fuel shuffling.

```
                    AVERAGE BURNUP OVER THE PRECEDING  465.00 DAY SUBINTERVAL
 NOTE - ALL ISOTOPES UNDERGOING FISSION ARE INCLUDED IN THE CALCULATION OF THE FOLLOWING
BURNUP FIGURES.

         AVERAGE BURNUP (ATOM %) OF EACH STAGE OF EACH PATH

 STAGE/REGION  1/C11B      2/C11B      3/C11B
               1.19312E+00  1.15421E+00  1.11847E+00
 STAGE/REGION  1/C21B      2/C21B      3/C21B
               1.05477E+00  1.02333E+00  9.94340E-01
                            .
                            .

         AVERAGE BURNUP (MWD/MT) OF EACH STAGE OF EACH PATH

 STAGE/REGION  1/C11B      2/C11B      3/C11B
               1.12484E+04  1.08815E+04  1.05446E+04
 STAGE/REGION  1/C21B      2/C21B      3/C21B
               9.94406E+03  9.64769E+03  9.37436E+03
                            .
                            .
```

Fig. 5.11. Example of Average Burnup Edit for Scattered Reloading without Shuffling

5.5. Average Fission and Instantaneous Total Powers

REBUS prints the average fission power over each subinterval and the instantaneous total power at each time node. In addition, the ratio of the instantaneous total power of a specific stage to the batch-averaged instantaneous power is printed. This ratio is called the power stage factor and is used in the subsequent thermal-hydraulics analysis to account for the discrete batch effects relative to the batch-averaged equilibrium cycle power for a scattered loading [35].

5.5.1. Average Fission Power

The average fission power in MW over a time interval Δt_n in stage τ of material l is calculated using the average burnup in MWD/MT over the time interval from Eq. (5.43) and the initial mass of fissionable isotopes from Eq. (5.13)

$$P_{l,\tau}^{n} = \frac{\mathrm{Bu}_{l,\tau}^{n,MWD} M_{l,0}^{fissionable}}{1000\Delta t_n}. \tag{5.44}$$

The time interval length is in days and the constant 1000 is used to convert the mass unit from kg to MT.

5.5.2. Instantaneous Power

The instantaneous total power at each time node is the power produced by fission and capture reactions in each region. The total power is calculated using the isotopic energy release per fission (EFISS) and that for capture (ECAPT) provided in the ISOTXS dataset. This power can

be consistent with the value displayed by DIF3D. That is, if several material types reside in a region for various stages, the sum of the power for all the stages of all the materials is equal to the region power calculated by DIF3D. However, REBUS computes the power only for the reaction types specified on card type 09 of A.BURN whereas DIF3D includes all reaction types provided in ISOTXS. For each active isotope i, the non-fission absorption rate per unit nuclide density is calculated by summing the contributions from all reactions (n,γ), (n,p), (n,α), $(n,2n)$, (n,d), and (n,t) or $\sum_g \sum_x \sigma_{ixg} \bar{\phi}_{kg}$, which for REBUS, will exclude those reactions that do not appear on a card type 09. The isotopic contribution of non-fission absorption rates to the instantaneous power density is thus calculated as the product of the non-fission microscopic absorption rate, the stage nuclide density, and the energy release per capture (ECAPT) from ISOTXS. If all reactions are not specified on card type 09, there will be some error in the REBUS result compared with the data provided by ISOTXS.

Figure 5.12 shows an example output of the average fission power and the instantaneous total power of each stage of each path in a problem with scattered loading without fuel shuffling.

```
     AVERAGE DAILY FISSION POWER IN MW OVER THE PRECEDING  465.00 DAY SUBINTERVAL

        AVERAGE POWER OF EACH STAGE OF EACH PATH

STAGE/REGION  1/C11B      2/C11B      3/C11B
              1.15435E-01  1.11670E-01  1.08212E-01
STAGE/REGION  1/C21B      2/C21B      3/C21B
              6.12296E-01  5.94048E-01  5.77217E-01
                           .
                           .

             INSTANTANEOUS TOTAL POWER IN MW AT TIME =   465.0000 DAYS

                    INSTANT POWER OF EACH STAGE OF EACH PATH

STAGE/REGION  1/C11B      2/C11B      3/C11B
              1.14095E-01  1.10497E-01  1.07182E-01
STAGE/REGION  1/C21B      2/C21B      3/C21B
              6.06834E-01  5.89346E-01  5.73174E-01
                           .
                           .
```

Fig. 5.12. Example of Average Fission Power and Instantaneous Total Power Edits

5.5.3. Power Stage Factor

For steady state thermal-hydraulics calculations that follow a given REBUS fuel cycle analysis, detailed heating information is needed. A coupled neutronics and gamma heating calculation is performed for one of the time points of the REBUS calculation. If the core compositions are determined from a REBUS equilibrium cycle analysis with a scattered loading scheme, the higher power density of fresh fuel assemblies will not be properly accounted for with the basic reconstructed time point DIF3D calculation. To account for this discrete batch effect given an equilibrium cycle (batch-averaged) scheme, the power stage factors of REBUS can be used when defining the power in the thermal-hydraulics calculation. The REBUS stage

factors convert the batch-averaged power in each region to the maximum assembly power of that region over the fuel residence time, which should correspond to the power of the fresh fuel assembly.

The power stage factor at a time node t_n is the ratio of the instantaneous total power of stage τ of material l to the batch-averaged power of material l written as

$$\mathrm{SF}_{l,\tau}^{n} = \frac{P_{l,\tau}^{n,total}}{P_{l,avg}^{n,total}}. \tag{5.45}$$

$P_{l,\tau}^{n,total}$ is the instantaneous total power of stage τ of material l obtained as described in Section 5.5.2 while $P_{l,avg}^{n,total}$ is the batch-averaged instantaneous total power of material l calculated using

$$P_{l,avg}^{n,total} = \frac{1}{S(l)} \sum_{\tau=1}^{S(l)} P_{l,\tau}^{n,total}. \tag{5.46}$$

Figure 5.13 shows an example output of the power stage factors for a problem with scattered loading without fuel shuffling. One should observe that the power decreases with increasing stage number for this loading scheme.

```
   INSTANTANEOUS TOTAL POWER/AVERAGE POWER AT TIME=   465.0000 DAYS

          POWER/AVG. POWER OF EACH STAGE OF EACH PATH

STAGE/REGION  1/C11B      2/C11B      3/C11B
              1.03168E+00  9.99145E-01  9.69174E-01
STAGE/REGION  1/C21B      2/C21B      3/C21B
              1.02891E+00  9.99256E-01  9.71836E-01                          .
                           .
                           .
```

Fig. 5.13. Example Output of Power Stage Factors

5.6. Peak Burnup and Peak Fast Fluence

REBUS calculates the local peak burnup and fast fluence (with a cutoff energy of 100 keV) for each stage of each path by evaluating the peak power and peak fast flux in the corresponding region using the surface- and cell-averaged power density and fast flux data in the SFEDIT dataset produced by DIF3D. For DIF3D-FD (and by extension TWODANT), the peak power density is the maximum value of the surface power densities. In DIF3D-Nodal and DIF3D-VARIANT, the peak power density is more complicated and starts by assuming the neutron flux within each node is separable by coordinate axis. In each node, the surface power densities are computed at a number of axial sampling planes (currently 11 equally spaced planes including the top and bottom surfaces), and the peak power density in the node is determined by the maximum value among these surface power densities. The peak fast flux is determined in a similar way to the peak power density. For DIF3D-VARIANT, one could choose to evaluate the peak correctly but this comes at significantly larger computational expense.

After each DIF3D calculation is complete, it stores the surface power densities and fast fluxes on the SFEDIT dataset. The number of surface power densities in a region R_k is the product of the number of meshes in that region, the number of surfaces per mesh, and the number of axial sampling planes within the mesh. In REBUS, the surface burnup is calculated for each surface power density by multiplying the surface power density and average burnup in the region together and dividing by the region-averaged power density. The peak burnup in the region is the peak value of these surface burnups. Similarly, the peak fast flux is determined by finding maximum value of the surface fast fluxes stored in SFEDIT while the peak fast fluence is determined by multiplying the peak fast flux by the time length of the subinterval.

5.6.1. Peak Burnup

Consider region R_k for which the SFEDIT dataset includes N_k^s surface power density evaluations. The power peaking factor of the j-th surface power density over a subinterval (t_{n-1}, t_n) is evaluated by dividing the average of the two surface power densities at t_{n-1} and t_n by the average of the two region-averaged power densities at t_{n-1} and t_n

$$f_{k,j}^n = \frac{S_{k,j}^n + S_{k,j}^{n-1}}{P_k^n + P_k^{n-1}}, \quad j = 1, 2, \cdots, N_k^s. \tag{5.47}$$

$S_{k,j}^n$ is the j-th surface power density in region R_k at time node t_n and P_k^n is the average power density of region R_k at time node t_n.

The burnup over subinterval (t_{n-1}, t_n) corresponding to the j-th surface power density is calculated by applying the power peaking factor from Eq. (5.47) to the average burnup in Eq. (5.43)

$$\mathrm{Bu}_{l,\tau,j}^{n,MWD} = \mathrm{Bu}_{l,\tau}^{n,MWD} f_{k,j}^n, \quad (l,\tau) \in R_k; \; j = 1, 2, \cdots, N_k^s. \tag{5.48}$$

The peak burnup of stage τ of material l over the subinterval (t_{n-1}, t_n) is determined as the maximum value of these surface burnup values

$$\mathrm{Bu}_{l,\tau,peak}^{n,MWD} = \max_j \{\mathrm{Bu}_{l,\tau,j}^{n,MWD} \mid j = 1, 2, \cdots, N_k^s, \; (l,\tau) \in R_k\}. \tag{5.49}$$

5.6.2. Peak Fast Fluence

Similar to the peak power density, the average value over a subinterval (t_{n-1}, t_n) of the j-th surface fast flux in region R_k is used

$$\bar{\phi}_{k,j}^{n,fast} = (\phi_{k,j}^{n,fast} + \phi_{k,j}^{n-1,fast})/2, \quad j = 1, 2, \cdots, N_k^s. \tag{5.50}$$

$\phi_{k,j}^{n,peak}$ is the j-th surface fast flux in region R_k at time node t_n.

The local surface fast fluence of stage τ of material l over the subinterval (t_{n-1}, t_n) is obtained by multiplying Eq. (5.50) by the time interval length Δt_n

$$\mathrm{FF}^n_{l,\tau,j} = \bar{\phi}^{n,fast}_{k,j} \Delta t_n \times 8.64 \times 10^4, \quad j = 1,2,\cdots,N^s_k;\ (l,\tau) \in R_k\,. \tag{5.51}$$

The time interval length is in days and the constant 8.64×10^4 is used to convert the time unit from days to seconds. The peak fast flux in region R_k is the maximum of these surface fast fluence values or

$$\mathrm{FF}^n_{l,\tau,peak} = \max_j \{\mathrm{FF}^n_{l,\tau,j} \mid j = 1,2,\cdots,N^s_k,\ (l,\tau) \in R_k\}\,. \tag{5.52}$$

Figure 5.14 shows an output excerpt of the peak burnup and peak fast fluence. The peak burnup is given in units of MWD/MT while and the peak fast fluence is given in units of neutrons/cm^2. These are the incremental values over the preceding time interval.

```
PEAK BURNUPS (MWD/MT) AND PEAK FAST FLUENCES (N/CM**2) OVER THE PRECEDING  465.00 DAY
SUBINTERVAL NOTE - ALL ISOTOPES UNDERGOING FISSION ARE INCLUDED IN THE CALCULATION OF THE
FOLLOWING BURNUP FIGURES.

         PEAK BURNUP (MWD/MT) OF EACH STAGE OF EACH PATH

STAGE/REGION  1/C11B      2/C11B      3/C11B
              1.39578E+04  1.35026E+04  1.30845E+04
STAGE/REGION  1/C21B      2/C21B      3/C21B
              1.37418E+04  1.33322E+04  1.29545E+04                              .
                            .
                            .

         PEAK FAST FLUENCE (N/CM**2) OF EACH STAGE OF EACH PATH

 STAGE/REGION  1/C11B      2/C11B      3/C11B
               2.99495E+22  2.99495E+22  2.99495E+22
 STAGE/REGION  1/C21B      2/C21B      3/C21B
               2.94251E+22  2.94251E+22  2.94251E+22
                            .
                            .
```

Fig. 5.14. Example of Peak Burnup and Peak Fast Fluence Edits

5.7. Reactor Summary Edits

Following the peak burnup and peak fast fluence edits, a reactor summary output is given for the mass balance, British definition breeding gain, and neutron balance. These summary edits are provided for the active isotopes in the core and the axial, radial, and internal blankets at the beginning and at the end of the subinterval. It should be noted that the headings BOC and EOC in these summary edits mean the beginning and the end of the subinterval, respectively (as opposed to beginning and end of cycle). The setup of these summary edits is completed using card types 29 to 31 from A.BURN.

Card type 29 allows the user to map specific areas in their geometry to the REBUS output areas. The REBUS output areas include inner core (ICORE), middle core (MCORE), outer core (OCORE), inner blanket (IBLKT), middle blanket (MBLKT), outer blanket (OBLKT), radial

blanket (RBLKT), axial blanket (ABLKT), control rods (CONTRL), and outer radial blanket (ORBLKT). If the area names on the type 07 cards of A.NIP3 are different from the default names given in parentheses above, the correspondence between the area names on card type 07 of A.NIP3 and the above nomenclature should be defined using card type 29 of A.BURN. If no areas are defined in the user problem, this reactor summary edit is not provided by REBUS.

Card type 30 is used to select the active isotopes included in the reactor summary output. It should be noted that any imbedded blanks in the isotope names should be removed on these cards. The number of isotopes for the summary edits are limited to 22 isotopes with defaults of: TH232, PA233, U-233, U-234, U-235, U-236, U-238, NP237, PU236, PU238, PU239, PU240, PU241, PU242, AM241, AM242, AM243, CM242, CM243, CM244, CM245, and CM246.

Card type 31 is used to classify each active isotope. Each isotope can be classified as one of the following: fissile, fertile, other actinide, fission product, structure, coolant, control, undefined, and special. If no card type 31 data is supplied, the card type 04 data from A.SUMMAR is used. If neither is provided, then the default definitions are used where U-233, U-235, PU239, and PU241 are defined as fissile isotopes and TH232, U-238, PU238, PU240, and PU242 are defined as fertile isotopes. While this information can also be provided via ISOTXS, that data is not used by REBUS.

If the isotope classifications are not setup properly, the most likely outcome is that the fissile production rate is overestimated. For example, if U-235, Pu239, and Pu241 are specified as fissile isotopes and U-238, Pu240, and Pu242 are specified as fertile isotopes, the neutron capture rate in Pu242 is included in the fissile production rate although it does not produce a fissile isotope.

5.7.1. Mass Balance

The mass balance output provides the isotopic inventories and the capture and fission reaction rates of fissile and fertile isotopes at the beginning and at the end of each subinterval for the following four collective areas: core (the sum of inner, middle, and outer cores), axial blanket, radial blanket (the sum of radial blanket and outer radial blanket), and internal blanket (sum of the inner, middle, and outer blankets). In this mass balance edit, the active isotope inventories (in kg) at the beginning and at the end of subinterval are given for the four collective areas. Then the capture and fission reaction rates of fissile and fertile isotopes at the beginning and at the end of subinterval are given for the four collective areas and the entire reactor. The capture reaction includes (n,γ), (n,p), (n,α), (n,d), and (n,t). The reaction rates are normalized to one neutron absorption in fissile isotopes, and the absolute absorption rate in fissile isotopes is given in the unit of numbers/s.

Figure 5.15 shows an output excerpt of the mass balance. In this problem, no blanket was defined and thus the edits are non-zero only for the core.

```
                                   MASS BALANCE, KG

              CORE              AXIAL BLANKET         RADIAL BLANKET       INTERNAL BLANKET
         BOC         EOC        BOC         EOC       BOC         EOC       BOC         EOC
U234_    0.520       0.510      0.000       0.000     0.000       0.000     0.000       0.000
U235_    5.752       4.588      0.000       0.000     0.000       0.000     0.000       0.000
U236_    6.052       6.048      0.000       0.000     0.000       0.000     0.000       0.000
U238_ 5792.363    5625.449      0.000       0.000     0.000       0.000     0.000       0.000

                              .
                              .

                       REACTOR          CORE        AXIAL BLANKET  RADIAL BLKT  INTERNAL BLKT
                       BOC    EOC     BOC    EOC     BOC    EOC     BOC    EOC    BOC    EOC
CAPTURES IN FISSILE ISOTOPES
               U235_  0.002  0.001   0.002  0.001   0.000  0.000   0.000  0.000  0.000  0.000
               PU239  0.153  0.152   0.153  0.152   0.000  0.000   0.000  0.000  0.000  0.000
               PU241  0.008  0.008   0.008  0.008   0.000  0.000   0.000  0.000  0.000  0.000
               TOTAL  0.162  0.162   0.162  0.162   0.000  0.000   0.000  0.000  0.000  0.000
FISSIONS IN FISSILE ISOTOPES
                              .
CAPTURES IN FERTILE ISOTOPES
                              .
FISSIONS IN FERTILE ISOTOPES
                              .
   BOC FISSILE ABSORPTIONS =  8.982648E+18       EOC FISSILE ABSORPTIONS =  9.023663E+18
```

Fig. 5.15. Example of Mass Balance Edits

5.7.2. British Definition Breeding Gain

The British definition breeding gain accounts for the difference in the reactivity value (and thus the critical mass) of various isotopes. It treats the different isotopes based upon equivalent amounts of ^{239}Pu, and hence has a direct connection with reactor doubling time [35]. In REBUS, instantaneous values are provided at each time node.

Consider the following perturbation of the one-group cross section of isotope i averaged over the core:

$$x_i = <\nu\sigma_f^i> - <\sigma_f^i> - <\sigma_c^i>, \tag{5.53}$$

where $<\ >$ denotes a core-averaged value. This cross section represents the reactivity increase (with some normalization factor) of a critical system when an atom of isotope i is introduced in the core. The equivalent worth of isotope i relative to ^{239}Pu is then defined as

$$w_i = (x_i - x_{U-238}) / (x_{Pu-239} - x_{U-238}), \tag{5.54}$$

where x_{U-238} and x_{Pu-239} are the perturbation cross sections of ^{238}U and ^{239}Pu, respectively. Using the equivalent worth in Eq. (5.54), the British definition breeding gain is defined as

$$G = \sum_i w_i (C_{i-1} - A_i) / \sum_i F_i, \quad A_i = F_i + C_i. \tag{5.55}$$

C_i and F_i denote the capture and fission rates of isotope i and thus C_{i-1} is the production rate of isotope i via the capture reaction of isotope $i-1$, and $C_{i-1} - A_i$ is the net production rate of isotope i.

Figure 5.16 shows an output excerpt of the British definition of breeding gain. The headings "BOC" and "EOC" mean the "beginning of time step" and the "end of time step," respectively. As was the case with the previous edits, only the core regions were setup for this example problem.

BRITISH DEFINITION BREEDING GAIN

	CORE		AXIAL BLANKET		RADIAL BLANKET		INTERNAL BLANKET	
	BOC	EOC	BOC	EOC	BOC	EOC	BOC	EOC
U234_	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
U235_	-0.0059	-0.0045	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
U236_	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NP237	0.0002	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PU236	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PU238	-0.0018	-0.0018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PU239	0.0200	-0.0088	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
.								
TOTAL	0.0360	0.0073	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Fig. 5.16. Example Edit of British Definition Breeding Gain

5.7.3. Neutron Balance

The neutron balance in the reactor summary edit is intended to provide an indication of the potential breeding capability of the system. Therefore, all of the values are normalized to one neutron absorption in fissile isotopes. Considering the neutron absorption and production rates in fissile and fertile isotopes separately, the neutron balance equation at a time node can be written as

$$L + A_{fissile} + A_{fertile} + A_{others} = \frac{1}{k}(\nu F_{fissile} + \nu F_{fertile}) . \quad (5.56)$$

$A_{fissile}$, $A_{fertile}$, and A_{others} denote the neutron absorption rates in fissile, fertile, and other isotopes, respectively. $\nu F_{fissile}$ and $\nu F_{fertile}$ are the neutron production rates due to fissile and fertile nuclide fissions, respectively. Finally, L is the leakage rate and k is the multiplication factor.

By dividing Eq. (5.54) by the neutron absorption rate in fissile isotopes and adding the production terms to both sides, Eq. (5.54) can be rewritten as

$$\frac{L}{A_{fissile}} + \frac{A_{others}}{A_{fissile}} + \left(1 - \frac{1}{k}\right)\left(\frac{\nu F_{fissile}}{A_{fissile}} + \frac{\nu F_{fertile}}{A_{fissile}}\right) = \left(\frac{\nu F_{fissile}}{A_{fissile}} + \frac{\nu F_{fertile} - F_{fertile}}{A_{fissile}} - 1\right) - \frac{C_{fertile}}{A_{fissile}} . \quad (5.57)$$

which can be written compactly as

$$l_{total} = l_{leakage} + l_{absorp} + l_{react} = \eta_{fissile} + \varepsilon_{fertile} - 1 - n_{breed} . \quad (5.58)$$

These terms are defined in Table 5.1 and is the neutron balance output produced in the REBUS reactor summary edit. Note that (n,2n) is not considered in this neutron balance, while it is included in the DIF3D neutron balance edits. The neutron leakage is thereby underestimated by

the (n,2n) reaction rate as the absorption rate is consistently calculated with the way the DIF3D neutron balance edits are done.

Table 5.1. Definition of Terms in REBUS Neutron Balance Edit

Eta of fissile isotopes	$\eta_{fissile} = \nu F_{fissile} / A_{fissile}$
Fertile fission bonus	$\varepsilon_{fertile} = (\nu F_{fertile} - F_{fertile}) / A_{fissile}$
Excess neutrons	$n_{excess} = \eta_{fissile} + \varepsilon_{fertile} - 1$
Total absorption loss	$l_{absorp} = A_{others} / A_{fissile}$
Reactivity control loss	$l_{react} = (1 - 1/k)(\nu F_{fisile} + \nu F_{fertile}) / A_{fissile}$
Leakage loss	$l_{leakage} = L / A_{fissile} = l_{total} - l_{react} - l_{absorp}$
Total loss	$l_{total} = n_{excess} - C_{fertile} / A_{fissile}$
Net neutrons for breeding	$n_{breed} = C_{fertile} / A_{fissile}$

The total absorptive loss in the neutron balance summary is the absorption in all isotopes but fissile and fertile isotopes. This is further separated into losses to structure, fission products, coolant, other actinides, and special isotopes according to the isotope classifications provided on card type 31 of A.BURN or card type 04 of A.SUMMAR. The reactivity control loss represents the excess neutrons to be removed for balancing the loss and production of neutrons. The total loss represents the neutrons lost to parasitic absorption and leakage. Fig. 5.17 shows an output excerpt of the neutron balance edit. The heading "BOC" and "EOC" mean the "beginning of time step" and the "end of time step," respectively.

```
                                    NEUTRON BALANCE

                    REACTOR         CORE        AXIAL BLKT  RADIAL BLKT INTER BLKT  CONTL RODS
                    BOC    EOC    BOC    EOC   BOC    EOC   BOC    EOC   BOC    EOC   BOC    EOC
ETA OF FISSILE      2.468  2.470  2.468  2.470 0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000
FERTILE FISS BONUS  0.465  0.453  0.465  0.453 0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000
EXCESS NEUTRONS     1.932  1.924  1.932  1.924 0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000
NEUTRON LOSSES
 STRUCTURE          0.000  0.000  0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000
 FISSION PRODUCTS   0.043  0.080  0.043  0.080 0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000
 COOLANT            0.000  0.000  0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000
 OTHER              0.103  0.106  0.103  0.106 0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000
 SPECIAL ISOTOPES   0.000  0.000  0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000
 TOTAL ABSORPTION   0.146  0.187  0.146  0.187 0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000
 REACTIVITY CONTL   0.010  0.016  0.010  0.016 0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000
LEAKAGE LOSS        0.739  0.715  0.739  0.715 0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000
TOTAL LOSSES        0.895  0.918  0.895  0.918 0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000
NET NEUTRONS        1.037  1.006  1.037  1.006 0.000  0.000 0.000  0.000 0.000  0.000 0.000  0.000
    FOR BREEDING

BOC FISSILE ABSORPTIONS =  8.982648E+18
EOC FISSILE ABSORPTIONS =  9.023663E+18
```

Fig. 5.17. Example Output of REBUS Neutron Balance Edits

The "net neutrons for breeding" output represents the instantaneous conversion ratio at the time node. However, since only fissile absorption and fertile capture reactions are considered, it is significantly larger than the instantaneous conversion ratio discussed in Section 5.2.1. In addition, the fissile destruction rate is significantly underestimated since it does not include the radioactive decay and (n,2n) reaction losses. For example, if the power density is not high enough, the decay of ^{241}Pu is greater than its absorption loss. The fissile production rate is assumed to be equal to the fertile capture rate, but since capture includes (n,γ), (n,α), (n,p), (n,d) and (n,t) reactions, the fissile production rate is overestimated.

5.8. Cumulative Edits

Following the edits for the final time node (i.e., $n = N$), the cumulative edits section of output can be identified with the heading "START OF CUMULATIVE EDITS." For each time node, the cumulative average burnup of each stage of each material from BOC to the current time node is printed in both atom % and MWD/MT in the same formats of those seen in Fig. 4.11. These burnup edits are followed by the burnup summary by area, which prints the average burnup in MWD/MT, the initial loading of fissionable isotopes in MT, and the average daily power in MW. The total average daily fission power summed over areas is also printed.

At the final time node (i.e., $n = N$), the peak discharge burnup in MWD/MT and the peak discharge fast fluence are printed before the burnup summary by area. For an equilibrium cycle problem, another column of average discharge burnup in MWD/MT is added to the burnup summary by area.

Note that in a non-equilibrium cycle enrichment search problem, multiple cumulative edits are printed since a multi-cycle problem should be run starting from the first cycle loaded with all fresh fuel up to the cycle of interest.

5.8.1. Cumulative Burnup

The first of these edits is for BOC or time node zero. The cumulative atom % burnup at BOC is defined as the overall burnup during the preceding stages

$$\mathrm{Bu}_{l,\tau,cum}^{0,at\%} = \sum_{s=1}^{\tau-1}\sum_{n=1}^{N} \mathrm{Bu}_{l,s}^{n,at\%} . \tag{5.59}$$

In Eq. (5.59), the inner sum over n represents the total burnup of each stage and the outer sum over s represents the total burnup over the preceding stages. Similarly, the burnup in MWD/MT is defined as

$$\mathrm{Bu}_{l,\tau,cum}^{0,MWD} = \sum_{s=1}^{\tau-1} \frac{\nu_{l,1} V_k}{8.64\times10^{7} \times C_{l,s}^{fiss/J} M_{l,0}^{fissionable}} \sum_{n=1}^{N} \mathrm{Bu}_{l,s}^{n,at\%} , \tag{5.60}$$

where the constant 8.64×10^{7} is used to convert from W-s/kg to MWD/MT.

Subsequent cumulative atom % burnups for the remaining N time nodes are obtained by adding the burnup over the subinterval in Eq. (5.40) to the cumulative burnup at BOC via

$$\mathrm{Bu}_{l,\tau,cum}^{n,at\%} = \mathrm{Bu}_{l,\tau,cum}^{0,at\%} + \sum_{m=1}^{n} \mathrm{Bu}_{l,\tau}^{m,at\%}, \quad 1 \le n \le N. \tag{5.61}$$

Similarly, the cumulative burnups in MWD/MT are obtained using

$$\mathrm{Bu}_{l,\tau,cum}^{n,MWD} = \mathrm{Bu}_{l,\tau,cum}^{0,MWD} + \sum_{m=1}^{n} \mathrm{Bu}_{l,\tau}^{m,MWD}, \quad 1 \le n \le N. \tag{5.62}$$

5.8.2. Cumulative Peak Burnup and Fluence

To determine the peak discharge burnup in region R_k, the surface stage burnup is calculated for each N_k^s surface power density by adding the surface burnup $\mathrm{Bu}_{l,\tau,j}^{n,MWD}$ in Eq. (5.48) as

$$\mathrm{Bu}_{l,\tau,j}^{cum,MWD} = \sum_{n=1}^{N} \mathrm{Bu}_{l,\tau,j}^{n,MWD}, \quad j = 1,2,\cdots,N_k^s. \tag{5.63}$$

The peak stage burnup is determined by the maximum value of these N_k^s surface stage burnups as

$$\mathrm{Bu}_{l,\tau,peak}^{cum,MWD} = \max_j \{\mathrm{Bu}_{l,\tau,j}^{cum,MWD} \mid j = 1,2,\cdots,N_k^s,\ (l,\tau) \in R_k\}. \tag{5.64}$$

The peak discharge burnup is obtained by adding the peak stage burnups

$$\mathrm{Bu}_{l,peak}^{d,MWD} = \sum_{\tau=1}^{S(l)} \mathrm{Bu}_{l,\tau,peak}^{cum,MWD}. \tag{5.65}$$

The surface stage fast fluence is calculated similarly for each of N_k^s surface fast flux by adding the surface fast fluence $\mathrm{FF}_{l,\tau,j}^{n}$ from Eq. (5.51)

$$\mathrm{FF}_{l,\tau,j} = \sum_{n=1}^{N} \mathrm{FF}_{l,\tau,j}^{n}, \quad j = 1,2,\cdots,N_k^s. \tag{5.66}$$

The peak stage fast fluence is the last N_k^s value of the surface fast fluence

$$\mathrm{FF}_{l,\tau,peak} = \max_j \{\mathrm{FF}_{l,\tau,j} \mid j = 1,2,\cdots,N_k^s,\ (l,\tau) \in R_k\}. \tag{5.67}$$

The peak discharge fast fluence is then obtained by adding the peak stage burnups as

$$\mathrm{FF}_{l,peak}^{d} = \sum_{\tau=1}^{S(l)} \mathrm{FF}_{l,\tau,peak}. \tag{5.68}$$

Figure 5.18 shows an output excerpt of the peak discharge burnup and fast fluence edits. The peak burnup is given in units of MWD/MT while the peak fast fluence is given in units of

neutrons/cm^2. These edits are followed by the burnup summary by area, which prints the average burnup in MWD/MT, the initial loading of fissionable isotopes in MT, and the average daily power in MW. The total average daily fission power summed over all areas is also printed.

```
CUMULATIVE PEAK BURNUP AND FAST FLUENCE AFTER 1 BURNUP SUBSTEPS,FROM 0.0000 DAYS TO
465.0000 DAYS.
                              PEAK DISCHARGE BURNUP (MWD/MT) OF EACH PATH

 PATH          PATH1         PATH2         PATH2         PATH2         PATH3         PATH3    ...
          4.05450E+04   4.00285E+04   3.10426E+04   3.31807E+04   1.80737E+03   2.73564E+03 ...

                          PEAK DISCHARGE FAST FLUENCE (N/CM**2) OF EACH PATH

 PATH          PATH1         PATH2         PATH2         PATH2         PATH3         PATH3    ...
          8.98484E+22   8.82752E+22   6.70631E+22   7.20968E+22   3.39661E+22   4.40901E+22 ...

                                    BURNUP SUMMARY BY AREA

AREA      AVERAGE BURNUP     INITIAL LOADING OF      AVERAGE DAILY      AVERAGE DISCHARGE
             (MWD/MT)     FISSIONABLE ISOTOPES (MT)    POWER (MW)        BURNUP (MWD/MT)

CORE        1.6021E+04           2.7200E-01            9.3714E+00          2.3820E+04
BLKT        5.8144E+02           4.0996E-01            5.1262E-01          9.0516E+02
RCTR        6.7394E+03           6.8197E-01            9.8840E+00          1.0045E+04
                                                      -----------
      TOTAL AVERAGE DAILY FISSION POWER (SUMMED OVER AREAS) =  1.9768E+01
```

Fig. 5.18. Example of Peak Discharge Burnup and Peak Discharge Fast Fluence Edits

5.9. Burnup Constraint Edits

If card type 06 of A.BURN is provided, an additional burnup edit is produced by REBUS each time the burnup limit is tested. If a burnup limit is specified for a path label, that limit is compared with the actual discharge burnup computed for each material type arising from that path. For a test group, a single overall discharge burnup over all the paths in the test group is computed and compared with the test limit.

As discussed in Sections 3.3.2 and 4.2.2, the numerator of the discharge burnup for material type l from a chosen path (or test group) is estimated in two different ways, depending on the burnup convergence criterion EPSG given on card type 03 of A.BURN. If EPSG is not negative, it is estimated from the number of fission products produced in each stage of that path (or all paths of the test group) via

$$\mathrm{BN}_{l,\tau}^{07} = \sum_{\tau=1}^{S(l)} \sum_{j\in BN} \sum_{i\in FP} B_{l,\tau}(i,j) n_{l,\tau,j}^{0} V_l \Big/ \sum_{i\in FP} \gamma_{jf}^{i} \,. \tag{5.69}$$

$B_{l,\tau}(i,j)$ represents the (i,j) element of the transmutation matrix $\mathbf{B}_{l,\tau}$ from Eq. (4.29)

$$\mathbf{B}_{l,\tau} = \prod_{n=1}^{N} \mathbf{B}_{l,\tau}^{n}, \quad l = 1,2,\cdots,L;\ \tau = 1,2,\cdots,S(l). \tag{5.70}$$

V_l is the volume of material type l and γ_{jf}^{i} is the yield fraction of isotope i from a fission of isotope j. In Eq. (5.69), i is summed over the fission products (FP) and j is summed over the isotopes defined using card type 07 of A.BURN. If the burnup convergence criterion EPSG on card type 03 of A.BURN is negative, the numerator includes the atoms destroyed by all processes or

$$\mathrm{BN}_{l,\tau} = \sum_{j \in BN} (n_{l,\tau,j}^{0} - n_{l,\tau,j}^{N}) V_l = \sum_{j \in BN} \left[n_{l,\tau,j}^{0} - \sum_{i=1}^{I} B_{l,\tau}(j,i) n_{l,\tau,i}^{0} \right] V_l \,. \tag{5.71}$$

The denominator is computed as the number of atoms initially present in material l

$$\mathrm{BD}_{l,\tau}^{08} = \sum_{i \in BD} n_{l,1,i}^{0} V_l \,. \tag{5.72}$$

The sum over i considers the isotopes defined using card type 08 of A.BURN. Without card types 07 and 08, the sum over j in Eq. (5.69) and the sum over i in Eq. (5.72) are taken over all isotopes that undergo the fission reaction.

Figure 5.19 shows an output excerpt of the burnup constraint that appears after the cumulative edits. In this example, the convergence criteria for the burnup constraint was set to 1.0 and no card type 07 and 08 data was provided. The discharge burnup for the burnup test group was calculated in the same way as the material burnup in the previous subsection, and because the 21.5% error is below the 100% error criteria, the cycle length was not adjusted to achieve the targeted burnup limit of 25%.

```
      BURNUP CALCULATION TO OBTAIN CONVERGENCE TO THE SPECIFIED BURNUP CONSTRAINTS
                          FOR BURN CYCLE TIME OF   465.00 DAYS


   PATH OR      SPECIFIED        ACTUAL         ALLOWABLE        ACTUAL
  TEST GROUP  BURNUP LIMIT  DISCHARGE BURNUP   ERROR (EPSG)      ERROR

    CORE       2.50000E-01     3.48921E-02     1.00000E+00     2.15108E-01

THE MAXIMUM DISCHARGE BURNUP OF  3.48921E-02 OCCURS IN CORE   AND
IS WITHIN THE ALLOWED ERROR LIMIT EPSG OF THE DESIRED BURNUP.
```

Fig. 5.19. Example of Burnup Constraint Edit

5.10. External Cycle Edits

The external fuel cycle model was described in detail in Section 2.2 and summarized graphically in Fig. 2.7. The external cycle edits are of three basic types: 1) the reprocessing and external feed summaries, 2) a complete external cycle summary which shows the mass flow of each of the active isotopes through the external cycle, and 3) a list of the external cycle time delays.

The external cycle calculations are initiated by first computing the total amount of each isotope i being discharged from the reactor from each material l. At the start of a burn step, the

stage 1 material is fresh fuel, stage 2 is once burned, and so on up to stage $S(l)$ the highest stage number for material l. At the end of this burn cycle, stage 1 material becomes stage 2 and so on, while stage $S(l)$ becomes stage $S(l)+1$ which is the stage being discharged from the reactor. The amount of isotope i (in atoms × 10^{-24}) in material l discharged from the reactor is given by

$$N_{l,i}^{disch} = n_{l,S(l)+1,i} V_l \,, \tag{5.73}$$

where $n_{l,S(l)+1,i} = n_{l,S(l),i}(T)$ is the atom density of isotope i of stage $S(l)$ of material l at EOC. The total amount of isotope i discharged from the reactor is given by

$$N_i^{disch} = \sum_{l=1}^{L} N_{l,i}^{disch} \,, \tag{5.74}$$

The new charge material is of density $n_{l,1i}^0 = n_{c,l,i}$, and hence the total amount of isotope i charged in this material is

$$N_{l,i}^{charge} = n_{l,1,i}^0 V_l \,. \tag{5.75}$$

The total amount of isotope i charged into the reactor is

$$N_i^{charge} = \sum_{l=1}^{L} N_{i,i}^{charge} \,. \tag{5.76}$$

The discharged material l is allowed to cool for a time t_l^c (card type 14 of A.BURN). The amount of isotope i in material l available after cooling is

$$N_{l,i}^{cool} = \sum_{m=1}^{I} \Lambda_{im}(t_l^c) N_{l,m}^{disch} \,, \tag{5.77}$$

where $\Lambda_{im}(t_l^c)$ is the (i,m) element of the decay matrix exponential $\mathbf{\Lambda}(t_l^c)$ in Eq. (3.94). The total amount of isotope i available after cooling is

$$N_i^{cool} = \sum_{l=1}^{L} N_{l,i}^{cool} \,. \tag{5.78}$$

A fraction of the cooled material l is sold, given by z_l in Eq. (3.33), with the remainder to be delivered to reprocessing plants. The amount of isotope i in material l to be delivered to reprocessing plants is

$$N_{l,i}^{plant} = (1 - z_l) N_{l,i}^{cool} \,. \tag{5.79}$$

The total amount of isotope i sold is

$$N_i^{sold} = \sum_{l=1}^{L} z_l N_{l,i}^{cool} \,, \tag{5.80}$$

while the total amount delivered to the reprocessing plants is

$$N_i^{plant} = \sum_{l=1}^{L} N_{l,i}^{plant} . \tag{5.81}$$

Using the fraction d_j^l of material l delivered to reprocessing plant j defined in Eq. (3.34), the total amount of isotope i delivered to reprocessing plant j is

$$N_i^{p,j} = \sum_{l=1}^{L} d_j^l N_{l,i}^{plant} . \tag{5.82}$$

Each of the J reprocessing plants can have a reprocessing time t_j^r (card type 16 of A.BURN). The amount of isotope i from plant j after this decay time is

$$N_{i,decay}^{p,j} = \sum_{m=1}^{I} \Lambda_{im}(t_j^r) N_m^{p,j} , \tag{5.83}$$

where $\Lambda_{im}(t_j^r)$ is the (i,m) element of the decay matrix exponential $\mathbf{\Lambda}(t_j^r)$ in Eq. (3.94). Using the recovery fraction r_i^j of isotope i from reprocessing plant j in Eq. (3.35), the amount of isotope i recovered from plant j is

$$N_i^{r,j} = r_i^j N_{i,decay}^{p,j} , \tag{5.84}$$

while the total amount of isotope i recovered from all reprocessing plants is

$$N_i^r = \sum_{j=1}^{J} N_i^{r,j} . \tag{5.85}$$

Using $N_i^{r,j}$ from Eq. (5.84) and following the procedure outlined in Sections 2.2 and 3.2, the atomic (i.e., volume) fractions of $N_i^{r,j}$ to be used for fabrication of CLASS 1 and CLASS 2 fuels of material type l can be calculated. Using these volume fractions $U_{r,j}^{l,1}$ in Eq. (3.68) for CLASS 1 and $U_{r,j}^{l,2}$ for CLASS 2 in Eq. (3.69), the elements of the delivery matrices $\mathbf{Q}_r$ in Eq. (3.84) and $\mathbf{Q}_f$ in Eq. (3.85) can be written as

$$Q_{j,i}^{l,r} = C_i^j U_{r,j}^{l,1} + (1 - C_i^j) U_{r,j}^{l,2} , \tag{5.86a}$$

where C_i^j is the fraction of isotope i assigned to CLASS 1 for reprocessing plant j, which is defined in Eq. (3.45).

Similarly, using the total amount of isotope i from external feed j, say $N_i^{f,j}$, the volume fractions of $N_i^{f,j}$ to be used for fabrication of CLASS 1 and CLASS 2 fuels of material type l can be calculated. With these volume fractions $U_{f,j}^{l,1}$ in Eq. (3.70) for CLASS 1 and $U_{f,j}^{l,2}$ for

CLASS 2 in Eq. (3.71), the elements of the delivery matrices $\mathbf{Q}_r$ in Eq. (3.84) and $\mathbf{Q}_f$ in Eq. (3.85) become

$$Q_{j,i}^{l,f} = C_i^j U_{f,j}^{l,1} + (1 - C_i^j) U_{f,j}^{l,2}, \tag{5.86b}$$

where C_i^j is the fraction of isotope i assigned to CLASS 1 for external feed j, which is defined in Eq. (3.47).

Using the delivery matrix elements in Eq. (5.86a), the total amount of isotope i from reprocessing plant j used in fabrication is

$$N_{i,fab}^{r,j} = \sum_{l=1}^{L} Q_{j,i}^{l,r} N_i^{r,j} . \tag{5.87}$$

The total amount of isotope i from all reprocessing plants used in fabrication is

$$N_{i,fab}^{r} = \sum_{j=1}^{J} N_{i,fab}^{r,j} . \tag{5.88}$$

The reprocessed material not used for fabrication is sold and is computed using

$$N_{i,sold}^{r} = N_i^r - N_{i,fab}^r . \tag{5.89}$$

Using the delivery matrix elements in Eq. (5.86b) for M external feeds, the total amount of isotope i for external feed j used in fabrication is

$$N_{i,fab}^{f,j} = \sum_{l=1}^{L} Q_{j,i}^{l,f} N_i^{f,j} , \tag{5.90}$$

The total amount of isotope i from all external feeds used in fabrication is

$$N_{i,fab}^{f} = \sum_{j=1}^{M} N_{i,fab}^{f,j} . \tag{5.91}$$

For a given material l, the total amount of isotope i from all reprocessing plants used in fabrication can be written with the delivery matrix elements in Eq. (5.86a) as

$$N_{l,i}^{r,fab} = \sum_{j=1}^{J} Q_{j,i}^{l,r} N_i^{r,j} , \tag{5.92}$$

where $N_i^{r,j}$ is the total amount of isotope i from reprocessing plant j defined in Eq. (5.84). The total amount of isotope i from all external feeds used in the fabrication of this material is

$$N_{l,i}^{f,fab} = \sum_{j=1}^{M} Q_{j,i}^{l,f} N_i^{f,j} . \tag{5.93}$$

where $N_i^{f,j}$ is the total amount of isotope i from external feed j.

Each material l is assigned to a path and thus can have its own fabrication time t_l^f (card type 12 of A.BURN). The amount of isotope i used in the fabrication of material l from reprocessing plants after the fabrication time decay is

$$N_{l,i,decay}^{r,fab} = \sum_{m=1}^{I} \Lambda_{im}(t_l^f) N_{l,m}^{r,fab}, \tag{5.94}$$

where $\Lambda_{im}(t_j^f)$ is the (i,m) element of the decay matrix exponential $\mathbf{\Lambda}(t_l^f)$ in Eq. (3.94). Similarly, the amount of isotope i from all external feeds used for fabrication of material l after the fabrication time decay time is

$$N_{l,i,decay}^{f,fab} = \sum_{m=1}^{I} \Lambda_{im}(t_l^f) N_{l,m}^{f,fab}. \tag{5.95}$$

The total amount of isotope i after fabrication is completed is

$$N_{i,decay}^{fab} = \sum_{l=1}^{L} (N_{l,i,decay}^{r,fab} + N_{l,i,decay}^{f,fab}). \tag{5.96}$$

The density of the fabricated charge material l is then

$$n_{l,i,decay}^{fab} = \frac{1}{V_l} (N_{l,i,decay}^{r,fab} + N_{l,i,decay}^{f,fab}). \tag{5.97}$$

To account for the preloading storage time t_l^s (card type 12 of A.BURN) this material must be decayed. The density of isotope i in fabricated material l after the preloading storage decay time is

$$n_{l,i,decay}^{storage} = \sum_{m=1}^{I} \Lambda_{im}(t_l^s) n_{l,m,decay}^{fab}. \tag{5.98}$$

This is the actual loaded charge of isotope i in material l. Eq. (4.53) is applied on this quantity when testing for convergence of the external cycle. The total amount of isotope i after preloading storage is

$$N_{i,decay}^{storage} = \sum_{l=1}^{L} n_{l,i,decay}^{storage}. \tag{5.99}$$

The preceding equations fully define all quantities in the external cycle output edit.

Figure 5.20 shows an output excerpt of the reprocessing plant and external feed summary. It shows the mass flows of a reprocessing plant REPC with a reprocessing time of 182.5 days and an external feed EFA. The four columns of the table for the reprocessing plant are

(1) Delivered amount to reprocessing plant j, $N_i^{p,j}$ in Eq. (5.82),

(2) Recovered amount from reprocessing plant j, $N_i^{r,j}$ in Eq. (5.84),

(3) Reprocessing loss, $N_i^{p,j} - N_i^{r,j}$, and

(4) Recovered amount used in fabrication, $N_{i,fab}^{r,j}$ in Eq. (5.87).

The table for the external feed includes the external feed amount used in fabrication, $N_{i,fab}^{f,j}$ in Eq. (5.90).

```
                REPROCESSING PLANT AND EXTERNAL FEED SUMMARY IN KILOGRAMS

          REPROCESSING PLANT REPC    REPROCESSING TIME = 1.82500E+02 DAYS.
ISOTOPE      DELIVERED        RECOVERED          WASTE            USED
U-235       1.08607E+00      1.08872E+00     -2.65919E-03      1.08320E+00
U-238       1.67252E+03      1.67252E+03     -4.68837E-06      1.67252E+03
NP237       9.85877E-01      0.00000E+00      9.85877E-01      0.00000E+00
PU238       9.33833E-01      9.37518E-01     -3.68467E-03      9.32762E-01
PU239       1.88299E+02      1.88297E+02      2.65954E-03      1.87341E+02
   .
   .
MATERIAL SUPPLIED BY EXTERNAL FEED EFA
       ISOTOPE      MATERIAL
       U-235       0.00000E+00
       U-238       1.36654E+02
       PU238       0.00000E+00
         .
         .
```

Fig. 5.20. Example of Reprocessing Plant and External Feed Summary

Figure 5.21 shows an output excerpt of the external cycle summary. The following quantities are shown:

(1) Charged amount, N_i^{charge} in Eq. (5.76),

(2) Discharged amount, N_i^{disch} in Eq. (5.74),

(3) Available amount after cooling, N_i^{cool} in Eq. (5.78),

(4) Sold amount before reprocessing, N_i^{sold} in Eq. (5.80),

(5) Delivered amount to reprocessing plants, N_i^{plant} in Eq. (5.81),

(6) Reprocessing loss, $N_{i,decay}^{p}$ in Eq. (5.83) minus N_i^r in Eq. (5.85),

(7) Recovered amount from reprocessing, N_i^r in Eq. (5.85)

(8) Recovered amount used in fabrication, $N_{i,fab}^r$ in Eq. (5.88),

(9) Sold amount after reprocessing, $N_{i,sold}^r$ in Eq. (5.89),

(10) External feed amount used in fabrication, $N_{i,fab}^f$ in Eq. (5.91),

(11) Fabricated amount, $N_{i,decay}^{fab}$ in Eq. (5.96), and

(12) Amount after preloading storage, $N_{i,decay}^{storage}$ in Eq. (5.99).

EXTERNAL CYCLE SUMMARY IN KILOGRAMS

ISOTOPE	CHARGED	DISCHARGED	AFTER COOLING	SOLD	DELIVERED TO REPROCESSING	LOST IN REPROCESSING
U-234	1.59331E-01	1.49385E-01	1.56513E-01	0.00000E+00	1.56513E-01	-3.63226E-03
U-235	2.24499E+00	1.08075E+00	1.08607E+00	0.00000E+00	1.08607E+00	-2.65919E-03
U-236	1.80592E+00	1.80259E+00	1.81091E+00	0.00000E+00	1.81091E+00	-4.16138E-03
U-238	1.83944E+03	1.67252E+03	1.67252E+03	0.00000E+00	1.67252E+03	-4.68837E-06
NP237	0.00000E+00	9.83214E-01	9.85877E-01	0.00000E+00	9.85877E-01	9.85877E-01
PU236	1.08042E-05	1.56332E-05	1.22616E-05	0.00000E+00	1.22616E-05	1.40241E-06
PU238	9.32781E-01	8.90699E-01	9.33833E-01	0.00000E+00	9.33833E-01	-3.68467E-03
PU239	1.87341E+02	1.88305E+02	1.88299E+02	0.00000E+00	1.88299E+02	2.65954E-03
	.					
	.					

ISOTOPE	RECOVERED IN REPROCESSING	REPROCESSED & USED IN MAKEUP	REPROCESSED & SOLD	EXTERNAL FEED USED IN MAKEUP	AFTER FABRICATION	AFTER STORAGE (NEW CHARGE)
U-234	1.60145E-01	1.59333E-01	8.12294E-04	0.00000E+00	1.59333E-01	1.59333E-01
U-235	1.08872E+00	1.08320E+00	5.52226E-03	1.16177E+00	2.24498E+00	2.24498E+00
U-236	1.81507E+00	1.80586E+00	9.20646E-03	0.00000E+00	1.80586E+00	1.80586E+00
U-238	1.67252E+03	1.67252E+03	-1.79761E-12	1.66914E+02	1.83944E+03	1.83944E+03
NP237	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
PU236	1.08592E-05	1.08041E-05	5.50803E-08	0.00000E+00	1.08041E-05	1.08041E-05
PU238	9.37518E-01	9.32762E-01	4.75531E-03	0.00000E+00	9.32762E-01	9.32762E-01
PU239	1.88297E+02	1.87341E+02	9.55084E-01	0.00000E+00	1.87341E+02	1.87341E+02
	.					
	.					

Fig. 5.21. Example of External Cycle Summary

5.11. Reactor Characteristics Summary Edits

The summary output for reactor characteristics and mass flows will appear at the end of a REBUS calculation. For an equilibrium cycle problem, it is enabled with card type 02 of A.STP027 and area definitions in card type 07 of A.NIP3 and, as necessary, card type 29 of A.BURN. In a non-equilibrium cycle problem, the summary of multiplication and power peaking factors is always provided even when the mass-flow edit is disabled.

The reactor characteristics summary output provides the following quantities at BOWC and EOEC: (1) multiplication factor, (2) power peaking factor, (3) peak power density, (4) peak flux, (5) peak fast flux, (6) breeding ratio, (7) power split among different portions of the reactor, (8) fissionable material loading, and (9) average discharge burnup.

The summary mass flow edits and the reactor summary edits discussed in Section 5.7 are controlled by the user input given on card types 29 to 34 of A.BURN. Card type 29 to 31 were discussed in Section 5.7. Card types 32 to 34 are used by the user to setup the summary mass flow edits which includes (1) reactor power both in MWe and MWt, (2) capacity factor, (3) cycle length, (4) external cycle time, (5) fractional loss in reprocessing, (6) core residence time, and (7) blanket residence time. Note that there are additional inputs that can be provided with these input cards which do not require additional discussion here.

The mass flow summary tables were designed for breeder reactor designs. The mass flows do not account for makeup feed coming from reprocessed fuel. In addition, only one external feed is considered and it only considers the standard 22 isotopes discussed in Section 5.7. The

summary mass flow edits are valid only when the same number of batches are used for all fuel paths. The residence times in core (CORE), radial blanket (RB), inner blanker (IB), and outer radial blanket (ORB) are specified with card type 34 of A.BURN in integer increments of cycles and applied for all paths.

Figure 5.22 shows an output excerpt of the reactor characteristics summary edit. It should be noted that the breeding ratio in this summary is not the breeding ratio over the total burn cycle but just the breeding ratio over the last time subinterval.

```
                              REACTOR CHARACTERISTICS SUMMARY
                              ===============================

                                                 BOEC      EOEC
                                               ----------------
                                          KEFF  1.00309   1.00514
                                PEAKING FACTOR  3.13667   3.02245

                                                PEAK FLUX        PEAK FAST FLUX (.GT. 0.1 MEV)
            PEAK POWER DENSITY, KW/L   10**15 N/CM**2/SEC          10**15 N/CM**2/SEC
                BOEC        EOEC         BOEC        EOEC           BOEC       EOEC
            ------------------------------------------------------------------------------
  INNER CORE  4.929E+02   5.998E+02    4.106E+00   4.547E+00      2.739E+00   3.015E+00
 MIDDLE CORE  5.042E+02   5.278E+02    4.067E+00   4.176E+00      2.738E+00   2.817E+00
  OUTER CORE  6.763E+02   6.523E+02    3.564E+00   3.469E+00      2.390E+00   2.301E+00

                         BREEDING   POWER SPLIT, %   FISSIONABLE   AVERAGE DISCHARGE
                          RATIO       BOEC  EOEC     LOADING, KG     BURNUP, MWD/KG
                         ------------------------------------------------------------
                    CORE  1.0032     96.81  96.89     6.9371E+03       7.270E+01
                   TOTAL  1.0032
```

Fig. 5.22. Example of Reactor Characteristics Summary Edit

Following the reactor characteristics summary edit, the “mass flow input data” are printed with no headings as shown in Fig. 5.23. Each row of this table contains the following data:

(1) EMW, THMW, CF, FPD, NPOW, NZONE from card type 32 of A.BURN
(2) NC, NRB, NIB, NFRAB, NFERRB, NFERIB, NORB from card type 34 of A.BURN
(3) EXT, FLOSS, EU235, NFIS from card type 33 of A.BURN, BOEC k-eff, and EOEC k-eff
(4) The breeding ratio in each of the following five areas (card type 29 of A.BURN): CORE = ICORE + MCORE + OCORE, AB = ABLKT, RB = RBLKT, IB = IBLKT + MBLKT + OBLKT, and ORB = ORBLKT
(5) The power fraction in the same five areas in (4)
(6) Initial heavy metal loading (in kg) in the same five areas in (4)
(7) The mass (in kg) for the standard 22 isotopes (card type 30 of A.BURN) in the five areas in (4) at BOEC followed by the mass for each isotope in each area at EOEC (a total of 220 values)
(8) The core feed (in kg) for the standard 22 isotopes

MASS FLOW INPUT DATA

1000.00000	2740.00000	0.75000	273.75000	2.00000	3.00000	
1.00000	5.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1.00000	0.00000	0.00200	1.00000	1.00309	1.00514	
1.00318	0.00000	0.00000	0.00000	0.00000		
100.00000	0.00000	0.00000	0.00000	0.00000		
6937.09082	0.00000	0.00000	0.00000	0.00000		
0.00000	0.00000	0.00000	0.52009	5.75224	6.05163	5792.36328
1.27775	0.00003	2.82142	624.81256	265.77335	31.04436	17.64185
1.96069	0.04822	0.70948	0.07120	0.00114	0.08192	0.00317
0.00009	0.00000	0.00000	0.00000	0.51014	4.58801	6.04830
5625.44873	2.26097	0.00004	2.77934	625.77588	266.18600	31.75442
17.66867	3.42638	0.10598	1.25868	0.13605	0.00284	0.19141
0.00972	0.00038	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
.						
.						

Fig. 5.23. Example of Reactor Characteristics Summary Edit

Figure 5.24 shows an output excerpt of the reactor performance and mass flow data, which comes after the mass flow input data. In this table the “calculated” values represent the amount of heavy metal supplied by the external feed while the “loading” values are the initial loading of fissionable isotopes. The “BOEC” values are the heavy metal inventory at the end of equilibrium cycle (BOEC) and “EOEC” values are the heavy metal inventory at the end of equilibrium cycle (EOEC).

CHECK HM BALANCE

	CORE	AB	RB	IB	ORB
CALCULATED	0.00				
LOADING	6937.09	0.00	0.00	0.00	0.00
BOEC	6750.93	0.00	0.00	0.00	0.00
EOEC	6588.15	0.00	0.00	0.00	0.00
BOEC - EOEC	162.78	0.00	0.00	0.00	0.00
LOADING - BOEC	186.16	0.00	0.00	0.00	0.00

Fig. 5.24. Example of Heavy Metal Balance Check Edit

Figure 5.25 shows an example summary table of reactor performance and mass flow data. The burnup (MWD/kg) for core, axial blanket, radial blanket, internal blanket, and outer radial blanket is calculated by multiplying the area specific power by the fuel residence time in the area. This value is slightly different from the MWD/MT burnup discussed in Section 5.4.2. If the same number of batches is used for all assemblies, it is a more appropriate MWD/MT burnup since a default energy conversion factor of 3.1×10^{10} fissions/W-s is used for the latter unless composition-dependent values are provided on card type 37 of A.NIP3.

The values in this summary table are prepared by considering ^{233}Pa, ^{233}U, ^{235}U, and ^{239}Pu as fissile isotopes and adjusting the breeding ratio. Unless the number of cycles for inner blanket residence time is less than -1.0, the breeding ratio is adjusted to take a credit for ^{233}Pa as

```
                          REACTOR PERFORMANCE AND MASS FLOW DATA
                          --------------------------------------
                                                          BREEDING    POWER    SPEC.POWER  BURNUP
                                                            RATIO     SPLIT    KWTH/KGHM   MWD/KG
REACTOR POWER, MWE/MWTH  : 1000/2740   CORE               1.003    100.000    197.489     54.063
FUEL RESIDENCE TIME, FPD :  1 X 274    AX.BLANKET         0.000      0.000      0.000      0.000
CAPACITY FACTOR, %       :    0        RD.BLANKET         0.000      0.000      0.000      0.000
                                       REACTOR TOTAL      1.003    100.000
BOC KEFF - EOC KEFF      :-2.048E-03
COMPOUND SYSTEM DOUBLING
               TIME, YRS :*****

                TOTAL     TOTAL
               FISSILE     HM
               -------   -------
INITIAL
LOADING,KG
  CORE             0.0       0.0
  AX.BLANKET       0.0       0.0
  RD.BLANKET       0.0       0.0
  TOTAL            0.0       0.0
EQUILIBRIUM
LOADING,KG/YR
  CORE             0.0       0.0
  AX.BLANKET       0.0       0.0
  RD.BLANKET       0.0       0.0
  TOTAL            0.0       0.0
EQUILIBRIUM
DISCHARGE,KG/YR
  CORE             0.0      -3.3
  AX.BLANKET       0.0       0.0
  RD.BLANKET       0.0       0.0
  TOTAL            0.0      -3.3
NET GAIN,KG/YR
  CORE             0.0      -3.3
  AX.BLANKET       0.0       0.0
  RD.BLANKET       0.0       0.0
  TOTAL            0.0      -3.3
```

Fig. 5.25. Example Edit of Reactor Performance and Mass Flow Data

$$\mathrm{BR}'_A = \mathrm{BR}_A + (\mathrm{BR}_{Rx} - 1)\frac{\Delta M_{Rx,PA233}}{\Delta M_{Rx,U\text{-}233} + \Delta M_{Rx,U\text{-}235} + \Delta M_{Rx,PU\,239}}, \tag{5.100}$$

where BR_A is the breeding ratio in area A defined by Eq. (5.31) and BR_{Rx} is the total reactor breeding ratio define by Eq. (5.32). The normalized increase in inventory of isotope i from BOEC to EOEC, $\Delta M_{Rx,i}$, is defined as

$$\Delta M_{Rx,i} = (M^N_{Rx,i} - M^0_{Rx,i}) \times \mathrm{NPOW}, \tag{5.101}$$

where $M^n_{Rx,i}$ is the total reactor loading of active isotope i at time node n in Eq. (5.11) and NPOW is the ratio of actual power to power used for the mass flow calculation specified with card type 32 of A.BURN. The breeding ratio and compound system doubling time are calculated with equal isotope weighting.

In the mass flow portion of the table, the “initial loading” is the external feed rate multiplied by the number of fuel residence cycles. The “equilibrium loading” is the external feed rate, and

the "equilibrium discharge" is the equilibrium loading plus the gain over a cycle. Finally, the "net gain" is the net gain over a cycle of the two masses. The net gain is obtained by multiplying the increase in inventory from BOEC to EOEC by the capacity factor and then dividing by the cycle length in full power years. This table includes only the isotopes whose initial loading, equilibrium loading, or net gain is greater than 0.1.

At the end, a reactor mass summary (in kg) per year is given for each active isotope. This mass flow per year includes the charged mass, the discharged mass, the amount destroyed in the reactor, the reprocessed amount used in re-fabrication, the amount of external feed used in re-fabrication, and the amount lost in reprocessing.

5.12. Edits of SUMMAR Module

As discussed earlier, the SUMMAR module can be used to produce useful engineering data needed in follow-on analysis activities. The SUMMAR module can be setup (card type 02 of A.SUMMAR) to provide the reaction summary edits after the DIF3D output stream for each time node. Note that the SUMMAR output edits can be controlled using card type 03 of A.STP027 to suppress this output at intermediate time nodes in an equilibrium problem.

The reaction summary edits in SUMMAR consist of three basic types: 1) reaction integrals in the core, 2) region and area reaction integrals, and 3) isotopic reaction integrals over areas. Effective one-group microscopic cross section data can be outputted via proper input to card type 01 of A.SUMMAR.

The fissile absorption, fissile source, fertile bonus, and parasitic absorptions are calculated using the isotope classifications provided on card type 04 of A.SUMMAR. The fissile mass, enrichment and conversion ratio are calculated using the isotope classifications given on card types 05 or 06 of A.SUMMAR. The default isotope classifications are different from those of REBUS such that U-233, U-235, PU239, PU241, and AM241 are fissile and the fertile isotopes are TH232, U-238, and PU240.

The power densities in the reaction summary edits of SUMMAR are computed using the total power conversion factor (PC) from the COMPXS dataset as is done in DIF3D. The power conversion factor can be modified by the user with card type 37 and card type 38 of A.NIP3. By default, the energy released per fission (EFISS) and capture (ECAPT) is taken from the ISOTXS dataset.

Figure 5.26 shows an output excerpt of the CORE area summary edits from SUMMAR. The CORE area is defined in terms of spatial regions using card type 07 of A.SUMMAR. If this input is not provided, all regions having a total atom density of fissionable isotopes greater than 7.0×10^{20} atoms/cm^3 are included in the core area. For a fixed source problem the k-effective is fixed to be 1.0 whereas eigenvalue problems report the preceding DIF3D computed value.

```
REACTION SUMMARY FROM J =  1 TO J = 33

K EFFECTIVE    1.003094435

POWER(WATTS)                          3.33333E+08
PEAK/AV. POWER  IN CORE               3.13667E+00
PEAK/AV. FISSION RATE  IN CORE        1.41716E+00
PERCENT FISS IN FERTILE MATL          2.31627E+01
FUEL ABSORP./FISS IN CORE             2.10219E+00
MEDIAN ENERGIES IN CORE
   SOURCE                             3.08930E+05
   ABSORPTION                         1.07193E+05
   FLUX                               1.85423E+05
CORE CONVERSION RATIO                 1.03517E+00
REACTOR BREEDING RATIO                1.03517E+00
FISSILE MATL- CORE/REACTOR ABS.       1.00000E+00
PEAK FLUX (NEUTRONS/CM2-SEC)          4.10581E+15
```

Fig. 5.26. Example of Core Reaction Summary Edits of SUMMAR

The median energies for the source, absorption, and flux in the core are determined as follows. Let X_g and I_X are the integral of a quantity X of interest over a group g and the entire energy domain, respectively. The group g that contains the median energy of X is determined by the smallest group number such that

$$\sum_{g'=1}^{g} X_{g'} > \frac{1}{2} I_X \,. \tag{5.102}$$

Approximating X in group g as a constant function of lethargy, the integral from the median energy E_m to the maximum energy E_0 is

$$\int_{E_m}^{E_0} X(E')dE' = \int_0^{u_m} X(u')du' = \sum_{g'=1}^{g-1} X_{g'} + \int_{u_{g-1}}^{u_m} X(u')du' \approx \sum_{g'=1}^{g-1} X_{g'} + \frac{u_m - u_{g-1}}{u_g - u_{g-1}} X_g = \frac{1}{2} I_X \,, \tag{5.103}$$

where $u = \ln(E_0 / E)$. Note that the energy group boundaries are taken from the ISOTXS dataset, including a non-zero lower bound for the last group. By solving Eq. (5.103) for the medium lethargy u_m, the median energy is found to be

$$u_m = u_{g-1} + \frac{(u_g - u_{g-1})}{X_g}\left[\frac{I_X}{2} - \sum_{g'=1}^{g-1} X_{g'}\right], \tag{5.104}$$

$$E_m = E_0 e^{-u_m} \,. \tag{5.105}$$

The group values of X_g for the source, absorption, and flux integrals in the core are calculated by summing the region reaction integrals:

$$X_g = \begin{cases} \sum_{k\in \text{CORE}} \nu\Sigma^k_{fg}\bar{\phi}_{kg}V_k, & \text{source} \\ \sum_{k\in \text{CORE}} \Sigma^k_{ag}\bar{\phi}_{kg}V_k, & \text{absorption} \\ \sum_{k\in \text{CORE}} \bar{\phi}_{kg}V_k, & \text{flux} \end{cases}. \tag{5.106}$$

It is noted that the source median energy of SUMMAR is not the median energy of fission neutrons. The correct median energy of fission neutrons is provided in the region and area balance integral edits of DIF3D. In DIF3D, the median energy is calculated with the fission neutron integral over region R_k defined as

$$X_{kg} = \begin{cases} \chi^k_g \sum_{g'=1}^{G} \nu\Sigma^r_{fg'}\bar{\phi}_{rg'}V_k, & \text{real} \\ \nu\Sigma^k_{fg} \sum_{g'=1}^{G} \chi^k_{g'}\bar{\phi}^*_{kg'}V_k, & \text{adjoint} \end{cases}. \tag{5.107}$$

Figure 5.27 shows an output excerpt of the region and area reaction summary edits of SUMMAR. The enrichment in this table is the fissile enrichment given in weight percent, while the enrichment of REBUS is the volume percent of the CLASS 1 material. In addition, the conversion and breeding ratios in this table represent the instantaneous conversion ratios computed using the fissile absorption and fertile capture rates only. The capture rate only includes the (n,γ) reaction. Consequently, the values in this table are significantly larger than the instantaneous conversion ratios reported by REBUS as described in Section 5.2.1.

			REGION TOTALS		
REGION	10 IC21D	11 IC21E	12 IC21F	13 IC21G	14 IC21H ...
REGION ID	CORE	CORE	CORE	CORE	CORE
VOLUME(LITERS)	4.82810E+00	4.82810E+00	4.82581E+00	4.82810E+00	4.82810E+00 ...
POWER(WATTS)	9.63290E+05	1.24552E+06	1.33191E+06	1.15106E+06	7.49154E+05 ...
FISS. SOURCE/K	8.41877E+16	1.09420E+17	1.17060E+17	1.01115E+17	6.55557E+16 ...
CONVERSN RATIO	1.27625E+00	1.24094E+00	1.23208E+00	1.24973E+00	1.30939E+00 ...
BREEDING RATIO	3.99762E-03	4.75620E-03	5.03638E-03	4.41911E-03	3.10706E-03 ...
FISS MASS(KG)	1.79837E+00	1.80857E+00	1.81191E+00	1.80219E+00	1.77780E+00 ...
HVY METAL(KG)	2.18750E+01	2.17201E+01	2.16630E+01	2.17704E+01	2.19859E+01 ...
ENRICHMENT, %	8.22111E+00	8.32672E+00	8.36404E+00	8.27817E+00	8.08611E+00 ...
PEAK FISS DENS	6.00749E+12	7.79915E+12	8.34660E+12	7.20778E+12	4.67750E+12 ...
AVE FISS DENS	6.00749E+12	7.79915E+12	8.34660E+12	7.20778E+12	4.67750E+12 ...
PEAK POWER DEN	4.92946E+02	2.76584E+02	2.80008E+02	2.66114E+02	2.04172E+02 ...
AVE POWER DEN	1.99517E+02	2.57974E+02	2.75998E+02	2.38409E+02	1.55165E+02 ...
PEAK/AVE POWER	2.47069E+00	1.07214E+00	1.01453E+00	1.11621E+00	1.31584E+00 ...
CAP POWER FRAC	4.07154E-02	3.69110E-02	3.66167E-02	3.69063E-02	3.96791E-02 ...
PEAK FLUX	3.42052E+15	4.05640E+15	4.10538E+15	3.91747E+15	3.04239E+15 ...
FLUX VOLUME	1.35739E+19	1.82343E+19	1.95340E+19	1.69399E+19	1.09754E+19 ...
%FLUX>100 KEV	6.15119E+01	6.45665E+01	6.48238E+01	6.45585E+01	6.22199E+01 ...
FISSILE ABS	2.81445E+16	3.44456E+16	3.67383E+16	3.17788E+16	2.13218E+16 ...
FISSILE SOURCE	6.65614E+16	8.46693E+16	9.05680E+16	7.81912E+16	5.12943E+16 ...
FERTILE BONUS	1.14980E+16	1.61262E+16	1.72586E+16	1.49371E+16	9.30140E+15 ...
PARASITIC ABS	4.64692E+15	5.73590E+15	6.19890E+15	5.17674E+15	3.30043E+15 ...
STRUCTURE	3.12815E+15	3.73794E+15	3.96619E+15	3.46216E+15	2.42833E+15 ...
FISS. PROD.	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00 ...
COOLANT	1.21879E+14	1.44472E+14	1.53061E+14	1.33611E+14	9.35478E+13 ...
OTHER	1.39689E+15	1.85348E+15	2.07965E+15	1.58097E+15	7.78552E+14 ...

Fig. 5.27. Example of Region and Area Reaction Summary Edits of SUMMAR

Figure 5.28 shows an output excerpt of the isotopic area reaction summary edits of SUMMAR. The isotopic reaction summary is provided only for isotopes who have a non-zero density.

```
                    REACTION INTEGRALS IN DIRECTION OF CALCULATION

    AREA          1  TCORE     2  ICORE     3  MCORE     4  OCORE     5  RFTOR
U235_     ENDF/B MAT. U235_      FISS(1)    ATOMIC MASS =  235.043922
     MASS(KG)    5.75178E+00  1.77750E+00  2.29696E+00  1.67732E+00  0.00000E+00
     GM-ATOM     2.44711E+01  7.56243E+00  9.77247E+00  7.13620E+00  0.00000E+00
     CAPTURES    1.69582E+16  6.38809E+15  6.77455E+15  3.79553E+15  0.00000E+00
     N2N PROD    1.02203E+14  3.36774E+13  4.46665E+13  2.38588E+13  0.00000E+00
     FISSIONS    6.60283E+16  2.44411E+16  2.70802E+16  1.45071E+16  0.00000E+00
     NUSIGF      1.62997E+17  6.02651E+16  6.69026E+16  3.58296E+16  0.00000E+00
     ALPHA       2.56832E-01  2.61367E-01  2.50166E-01  2.61633E-01  0.00000E+00
     MACRO CAP   4.14839E-06  4.50311E-06  4.02749E-06  3.84466E-06  0.00000E+00
     MACRO FIS   1.61522E-05  1.72291E-05  1.60993E-05  1.46949E-05  0.00000E+00
     MACRO N2N   1.25006E-08  1.18700E-08  1.32772E-08  1.20838E-08  0.00000E+00
     NU BAR      2.46860E+00  2.46573E+00  2.47053E+00  2.46980E+00  0.00000E+00
     ETA         1.96414E+00  1.95481E+00  1.97616E+00  1.95762E+00  0.00000E+00
     MICRO CAP   4.21255E-01  4.29587E-01  3.96431E-01  4.31865E-01  0.00000E+00
     MICRO FIS   1.64020E+00  1.64361E+00  1.58467E+00  1.65065E+00  0.00000E+00
     MICRO N2N   1.26940E-03  1.13237E-03  1.30689E-03  1.35736E-03  0.00000E+00
  .
  .
FE56_     ENDF/B MAT. FE56_          (5)    ATOMIC MASS =   55.934505
     MASS(KG)    1.81443E+03  5.26770E+02  7.02360E+02  5.85300E+02  2.41143E+02
     GM-ATOM     3.24385E+04  9.41762E+03  1.25568E+04  1.04640E+04  4.31117E+03
     CAPTURES    3.47435E+17  1.22941E+17  1.39662E+17  8.48321E+16  2.94145E+16
     N2N PROD    6.99079E+14  2.17205E+14  2.98694E+14  1.83179E+14  2.04336E+13
     MACRO CAP   8.49912E-05  8.66642E-05  8.30292E-05  8.59303E-05  4.28263E-04
     MACRO N2N   8.55060E-08  7.65564E-08  8.87873E-08  9.27753E-08  1.48753E-07
     MICRO CAP   6.51077E-03  6.63893E-03  6.36046E-03  6.58270E-03  7.96292E-03
     MICRO N2N   6.55020E-06  5.86462E-06  6.80157E-06  7.10707E-06  2.76584E-06
  .
  .
```

Fig. 5.28. Example of Isotopic Area Reaction Summary Edits of SUMMAR

5.13. Scaling Information Edits for Fixed Source Problems

As discussed in Section 2.4, for a subcritical fixed source problem, the neutron flux and external source intensity are re-normalized to the user-specified power. To accomplish constant power depletion, the fixed source intensity is scaled appropriately to compensate for changes in the multiplication factor. If a FIXSRC file exists, the FXSCAL module is invoked following the neutronics calculation. By calculating the reactor power using the neutron flux solution saved in the RTFLUX dataset, FXSCAL determines the power scaling factor to produce the user-specified power. FXSCAL scales the neutron flux solution stored in RTFLUX, RZFLUX (real zone flux instead of r-z), and, if present, NHFLUX, along with the external source file FIXSRC. FXSCAL also calculates the multiplication factor k_s in Eq. (2.3) using the external source intensity and the fission neutron production rate. The calculated k_s value is stored on the RTFLUX, RZFLUX, and NHFLUX datasets as appropriate. FXSCAL prints the information about this scaling calculation.

Figure 5.29 shows an output excerpt of the scaling information edit for a subcritical fixed source problem. The information about the flux solution file is first presented. The "total external source" is the external neutron source intensity (in neutrons/s), and the "total fission neutrons" is the total number of fission neutrons produced per second. The "multiplication factor" is the k_s value evaluated with these external and fission neutron intensities. The "total power" is the power level in watts calculated with the flux solution before scaling. The two values on rows "RZFLUX" and "RTFLUX" are the power level and multiplication factor stored in the RZFLUX and RTFLUX, respectively, before they are rewritten by FXSCAL. The two values on the row with heading "DIF3D" are the user-specified power (in watts) and k-effective values from card type 06 of A.DIF3D.

DIF3D sets the multiplication factor to 1.0 for a fixed source problem, and thus the multiplication factors in RTFLUX and RZFLUX are 1.0. Moreover, since a fixed source problem has a unique solution, DIF3D does not perform the power normalization calculation and sets the total power in RTFLUX to the user input value and the value in RZFLUX to the initialization value of 1.0. It can be seen that the total power calculated with the flux solution (196.03 MW) is significantly higher than the user-specified value (140 MW), and thus the external source and flux distributions are scaled by a factor 140/196.03 = 0.714176.

```
                        ***** FXSCAL HAS BEEN ENTERED *****

*** RTFLUX USED IN FLUX NORMALIZATION ***

    HOLLERITH FILE NAME = RTFLUX
    USER IDENTIFICATION = wyang
    FILE VERSION NO.    =      1
    FILE REFERENCE NO.  =     82
    LOGICAL UNIT NO.    =      9


*** MULTIPLICATION FACTOR AND TOTAL POWER ***

    TOTAL EXTERNAL SOURCE  =  5.68087E+17
    TOTAL FISSION NEUTRONS =  1.83933E+19
    MULTIPLICATION FACTOR  =  9.70040E-01
    TOTAL POWER            =  1.96030E+08

    RZFLUX :   1.00000E+00  1.00000E+00
    RTFLUX :   1.40000E+08  1.00000E+00
    DIF3D  :   1.40000E+08  1.00000E+00
```

Fig. 5.29. Example of Scaling Information Edits for Fixed Source Problem

Acknowledgments

The authors are grateful to Adam Nelson for reviewing the report and providing valuable comments.

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Appendix A. Description of BCD Input Dataset A.STP027

```
C*********************************************************************
C                                                                     -
C                       Latest version 11/09/05
C                                                                     -
CF          A.STP027                                                  -
CE          FUEL CYCLE STANDARD PATH BCD INPUT                        -
C                                                                     -
CN                      THIS IS A USER SUPPLIED BCD DATA SET.  THE    -
CN                      LIST FOR EACH RECORD IS GIVEN IN TERMS OF THE -
CN                      BCD FORMAT OF THE DATA CARD.  COLUMNS 1-2     -
CN                      NORMALLY CONTAIN THE CARD TYPE NUMBER.        -
CN                                                                    -
CN                      A.STP027 NEED NOT BE SUPPLIED AT ALL - OR     -
CN                      ANY CARD TYPE MAY BE OMITTED.                 -
CN                                                                    -
C                                                                     -
C                                                                     -
CN                 ***  CARD TYPE DIRECTORY  ***                      -
CN                                                                    -
CN    TYPE                     CONTENTS                               -
CN    ====    ================================================       -
CN     01     GENERAL PROBLEM SPECIFICATIONS                         -
CN     02     GENERAL EDIT SPECIFICATIONS                            -
CN     03     SELECTIVE EDIT SPECIFICATIONS                          -
CN     04     A.DIF3D TYPE 02 CARD MODIFICATIONS                     -
CN     05     LOGIC FLOW MODIFICATIONS                               -
CN     06     OPTION FOR FLUX FILE SAVING ON STACK FILE              -
C                                                                     -
C*********************************************************************


C---------------------------------------------------------------------
CR          GENERAL PROBLEM SPECIFICATIONS (TYPE 01)                  -
C                                                                     -
CL    FORMAT-----(I2,4X,11I6)                                       -
C                                                                     -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY              -
CD  =  =======  ========================================================-
CD  1   1-2     01                                                    -
CD                                                                    -
CD  2   7-12    0...DO NOT ACTIVATE ERRSET (DEFAULT).                 -
CD              1...ACTIVATE ERRSET TO FORCE AN ABEND UPON ENCOUNTERING-
CD                  ANY ERROR DETECTED BY THE FORTRAN EXTENDED ERROR  -
CD                  HANDLING FACILITY.                                -
CD                                                                    -
CD  3   13-18   0...NORMAL EIGENVALUE PROBLEM (DEFAULT).              -
CD              1...EXECUTION ONLY THROUGH THE FUEL CYCLE INPUT       -
CD                  PROCESSOR (FCI002) FOR DEBUGGING OF A NEW CASE.   -
CD                  NOT PERTINENT FOR A RESTART PROBLEM.              -
CD              2...FIXED SOURCE PROBLEM                              -
CD                                                                    -
CD  4   19-24   0...DISABLE CRITICALITY SEARCH SPECIFIED BY           -
CD                  A.NIP3 (DEFAULT).                                 -
CD              1...ENABLE CRITICALITY SEARCH.                        -
```

```
CD                                                                          -
CD  5   25-30   0...EQUILIBRIUM PROBLEM (DEFAULT).                          -
CD              1...NONEQUILIBRIUM PROBLEM.                                 -
CD                                                                          -
CD  6   31-36   0...ENABLE NEUTRONICS (DEFAULT).                           -
CD              1...DISABLE NEUTRONICS - I.E. ASSUME THE ORIGINAL FLUX      -
CD                  DISTRIBUTION, AS COMPUTED BY THE FIRST NEUTRONICS       -
CD                  CALCULATION, OR AS GIVEN BY THE RZFLUX DATA SET         -
CD                  THAT IS PROVIDED IN THE BLOCK=OLD DATA SETS, IS         -
CD                  APPLICABLE THROUGHOUT THE PROBLEM.  THE                 -
CD                  FLUX LEVEL IS RENORMALIZED AT EACH SUBINTERVAL SO       -
CD                  AS TO MAINTAIN A CONSTANT POWER LEVEL. PERTINENT        -
CD                  ONLY FOR NONEQUILIBRIUM PROBLEMS (I.E. A 1 IN COLS.-
CD                  25-30)                                                  -
CD              2...USE THE TWODANT CODE TO OBTAIN THE FLUX SOLUTION.       -
CD                                                                          -
CD              NOTES ON THE USE OF THIS OPTION:                            -
CD              1. COLS. 31-36 MUST BE 0 OR 2 IF COLS. 25-30 ARE 0.         -
CD              2. IF COLS. 31-36 ARE 1, THEN COLS. 61-66 ON CARD           -
CD                 TYPE 02 OF DATA SET A.BURN SHOULD BE 0.                  -
CD              3. A NEUTRONICS SOLUTION IS ALWAYS OBTAINED AT THE          -
CD                 END OF THE BURN STEP EVEN IF COLS. 31-36 ARE 1.          -
CD              4. IF RZFLUX APPEARS AMONG THE BLOCK=OLD DATA SETS,         -
CD                 COLS. 31-36 ARE IGNORED AND THE SUPPLIED RZFLUX IS       -
CD                 USED THROUGHOUT THE PROBLEM WITH RENORMALIZATION TO      -
CD                 MAINTAIN CONSTANT POWER.                                 -
CD              5. WARNING! IN THE CASE OF A RESTART PROBLEM,               -
CD                 THE RZFLUX DATA SET IS AUTOMATICALLY                     -
CD                 RECREATED FROM THE RESTART DATA SET RFILES. HENCE        -
CD                 ANY SUPPLIED RZFLUX DATA SET WILL BE OVERWRITTEN.        -
CD              6. IF COLS. 31-36 ARE 2, THEN COLS. 37-42 MUST BE           -
CD                 1 TO OBTAIN AN ACCURATE TWODANT SOLUTION UTILIZING       -
CD                 THE FULL SCATTERING MATRIX.                              -
CD                                                                          -
CD  7   37-42   NO LONGER IN USE. ENTRIES ARE IGNORED AND SET TO 1.         -
CD              1...USE THE ORIGINAL ISOTXS AND NDXSRF DATA SETS            -
CD                                                                          -
CD  8   43-48   0...NO PERIODIC SAVES (DEFAULT).                           -
CD              N...MAKE A PERIODIC SAVE EVERY X/N MINUTES WHERE X IS       -
CD                  THE PROBLEM JOB TIME AS PUNCHED ON THE JOB CARD.        -
CD                                                                          -
CD  9   49-54   0...NORMAL PROBLEM (DEFAULT).                              -
CD              N...TERMINATE PROBLEM WITH A WRAPUP AFTER N NEUTRONICS      -
CD                  SOLUTIONS HAVE BEEN COMPLETED.                          -
CD             -N...MAKE A PERIODIC SAVE AFTER EVERY N NEUTRONICS           -
CD                  SOLUTIONS.                                              -
CD                                                                          -
CD  10  55-60   0...DO NOT EXECUTE A STANDALONE MASS FLOW SUMMARY EDIT      -
CD              1...EXECUTE A STANDALONE MASS FLOW SUMMARY EDIT             -
CD                                                                          -
CD  11  61-66   AVAILABLE TIME FOR THE PROBLEM IN SECONDS                   -
CD              (DEFAULT=100000)                                            -
CD                                                                          -
CD  12  66-72   0...NORMAL PROBLEM (DEFAULT).                              -
```

```
CD              1...HIGH BURNUP PROBLEM.                                -
CD              2...PERFORM ONE PASS THROUGH THE EXTERNAL CYCLE IN THE -
CD                  PRELIMINARY SEARCH                                  -
C                                                                       -
CN              THE AVAILABLE TIME IN COLS. 61-66 SHOULD NORMALLY NOT  -
CN              BE SPECIFIED SINCE THE REMAINING LIMITING TIME FOR THE -
CN              PROBLEM IS OBTAINED FROM THE SYSTEM.  HOWEVER, IF      -
CN              COLS. 61-66 ARE NOT 0, THE VALUE SUPPLIED WILL BE USED -
CN              TO COMPUTE A VALUE FOR THE REMAINING LIMITING TIME     -
CN              WHICH WILL BE COMPARED WITH THE VALUE OBTAINED FROM    -
CN              THE SYSTEM.  THE DETERMINATION OF WHEN A PROBLEM       -
CN              WRAPUP IS REQUIRED WILL MAKE USE OF THE SMALLER OF     -
CN              THE TWO VALUES OF THE REMAINING LIMITING TIME.         -
CN              NOTE THAT WHEN A LEGITIMATE VALUE FOR THE REMAINING    -
CN              LIMITING TIME CAN NOT BE OBTAINED FROM THE SYSTEM      -
CN              (AS FOR EXAMPLE IN THE CASE OF THE EXPORT VERSION      -
CN              OF REBUS-3) USE OF COLS. 61-66 IS ESSENTIAL TO AVOID   -
CN              EXCEEDING THE AVAILABLE TIME FOR A PROBLEM WITHOUT     -
CN              OBTAINING A RESTART DATA SET.                          -
CN                                                                     -
CN              THE USE OF THE PERIODIC SAVE OPTION DOES NOT DISABLE   -
CN              THE SAVE WHICH IS MADE IF A JOB RUNS OUT OF TIME.      -
CN                                                                     -
CN              A RESTART PROBLEM IS INDICATED BY PUTTING THE          -
CN              DATA SET RFILES IN THE 'BLOCK=OLD' DSIB.               -
CN              RESTART was permanently disabled by MAS on 2013/01     -
CN                No one has done this in a decade or more and we do   -
CN                not have a clear example of how to do it. I also     -
CN                disabled the NHFLUX/RZFLUX/RTFLUX writes which will  -
CN                prevent it from working anyway                       -
CN                                                                     -
CN              THE DATA SETS ISOTXS AND NDXSRF ARE ON LOGICAL UNIT    -
CN              NUMBERS 35 AND 37, RESPECTIVELY.                       -
CN                                                                     -
CN              IF COLS. 55-60 ARE 1, ONLY THE STANDALONE MASS FLOW    -
CN              SUMMARY EDIT WILL BE EXECUTED AND DATA SET A.MASFLO    -
CN              SHOULD BE PROVIDED.  A NORMAL EQUILILIBRIUM REBUS-3    -
CN              PROBLEM WILL PROVIDE A MASS FLOW SUMMARY EDIT AS PART  -
CN              OF ITS NORMAL OUTPUT DEPENDING UPON THE DATA IN DATA   -
CN              SET A.BURN CARD TYPES 31-34.  IF COLS. 31-36 ON DATA   -
CN              SET A.STP027 CARD TYPE 02 ARE 1, THE INPUT FOR THE MASS-
CN              FLOW SUMMARY EDITS WILL BE PUNCHED FOR SUBSEQUENT USE  -
CN              WITH A STANDALONE EXECUTION OF THE MASS FLOW SUMMARY.  -
CN                                                                     -
CN              IF COLS. 66-72 ARE 1, THE MAXIMUM NUMBER OF CYCLIC     -
CN              MODE ITERATIONS SUPPLIED IN COLS. 67-72 ON CARD TYPE   -
CN              02 OF DATA SET A.BURN IS USED DURING THE INTERMEDIATE  -
CN              SEARCH.  ALSO, IF COLS. 66-72 ARE 1, FOR AN ENRICHMENT -
CN              SEARCH, THE USER SUPPLIED CONVERGENCE CRITERION EPSF   -
CN              ON THE DATA SET A.BURN TYPE 04 CARD IS TEMPORARILY      -
CN              INCREASED BY A FACTOR OF 50 DURING THE PRELIMINARY     -
CN              SEARCH PROCEDURE. COLS. 66-72 SHOULD BE SET TO 1 FOR   -
CN              PROBLEMS HAVING ATOM PERCENT BURNUPS GREATER THAN THE  -
CN              ORDER OF 30 A/O.                                       -
```

```
CN                                                                      -
CN              IF COLS. 66-72 ARE 2, ONE PASS IS MADE THROUGH THE      -
CN              EXTERNAL CYCLE IN THE PRELIMINARY SEARCH. THIS OPTION   -
CN              IS RECOMMENDED WHEN THE REACTIVITY OF THE EXTERNAL      -
CN              FEED IS VERY DIFFERENT FROM THAT OF THE REPROCESSED     -
CN              FUEL.                                                   -
CN                                                                      -
CN              IF COLS. 13-18 ARE 2, THE USER MUST PROVIDE A FIXSRC    -
CN              (FIXED SOURCE) FILE APPROPRIATE FOR THE PROBLEM BEING   -
CN              SOLVED.                                                 -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          GENERAL EDIT SPECIFICATIONS (TYPE 02)                       -
C                                                                       -
CL    FORMAT-----(I2,4X,11I6)                                           -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     02                                                      -
CD                                                                      -
CD  2   7-12    0...SUPPRESS NEUTRONICS EDITS UNTIL LAST                -
CD                  PASS (DEFAULT).                                     -
CD              1...ENABLE NEUTRONICS EDITS.                            -
CD                                                                      -
CD  3   13-18   0...ENABLE REACTION SUMMARY EXECUTION (DEFAULT).        -
CD              1...DISABLE REACTION SUMMARY EXECUTION.                 -
CD                                                                      -
CD  4   19-24   0...SUPPRESS EDITS OF OPEN DATA SETS AFTER COMPLETION  -
CD                  OF EACH MODULE (DEFAULT).                           -
CD              1...ENABLE EDITS OF OPEN DATA SETS AFTER COMPLETION     -
CD                  OF EACH MODULE.                                     -
CD                                                                      -
CD  5   25-30   0...SUPPRESS EDITS OF ATOM DENSITIES USED IN EACH       -
CD                  NEUTRONICS SOLUTION (DEFAULT).                      -
CD              1...ENABLE EDITS OF ATOM DENSITIES IN THE FINAL PASS    -
CD                  WITH FULL EDITS.                                    -
CD             -1...ENABLE EDITS OF ATOM DENSITIES AT ALL TIMES.        -
CD              2...SAME AS 1 BUT ONLY EDIT ON AUXILIARY OUTPUT FILE.   -
CD             -2...SAME AS -1 BUT ONLY EDIT ON AUXILIARY OUTPUT FILE.  -
CD                                                                      -
CD  6   31-36   0...DO NOT PUNCH THE MASS FLOW SUMMARY DATA            -
CD                  (DEFAULT)                                           -
CD              1...PUNCH THE MASS FLOW SUMMARY DATA                    -
CD                                                                      -
CD  7   37-42   0...SUPPRESS EDITS OF ZNATDN DATA SET (DEFAULT).       -
CD              1...ENABLE ZNATDN EDITS.                                -
CD                                                                      -
CD  8   43-48   0...SUPPRESS MASS FLOW EDITS (DEFAULT).                -
CD              1...ENABLE MASS FLOW EDITS.                             -
CD                                                                      -
CD  9   49-54   0...DO NOT INVOKE UDOIT1 MODULE (DEFAULT).              -
```

```
CD              1...INVOKE UDOIT1 MODULE.                                -
CD                                                                       -
CD  10  55-60   0...DO NOT INVOKE UDOIT3 MODULE (DEFAULT).               -
CD              1...INVOKE UDOIT3 MODULE.                                -
CD                                                                       -
CD  11  61-66   0...PROVIDE FULL EDITS FROM ALL MODULES (DEFAULT).       -
CD              1...SUPPRESS EDITS COMPLETELY FROM MODULES MODDIF AND    -
CD                  RESNDX.  ALSO, EDITS FROM MODULE FCC004 WILL BE      -
CD                  REDUCED EXCEPT FOR THE FINAL PASS WITH FULL          -
CD                  EDITS.                                               -
CD                                                                       -
CD  12  67-72   0...NORMAL PROBLEM (DEFAULT).                            -
CD              1...TERMINATE THE PROBLEM AFTER EXECUTING GNIP4C.        -
C                                                                        -
CN              IF COLS. 43-48 ARE 1, CARD TYPES 32-34 OF DATA SET       -
CN              A.BURN SHOULD BE SUPPLIED.                               -
CN                                                                       -
CN              COLS. 61-66 WILL ONLY AFFECT THE EDITS ROUTED TO         -
CN              THE STANDARD PRINT FILE.  THE AUXILIARY PRINT FILE       -
CN              OUTPUT, IF ANY, WILL CONTAIN ALL OF THE EDITS.           -
CN                                                                       -
C                                                                        -
C-------------------------------------------------------------------------

C-------------------------------------------------------------------------
CR          SELECTIVE EDIT SPECIFICATIONS (TYPE 03)                      -
C                                                                        -
CL    FORMAT-----(I2,4X,11I6)                                            -
C                                                                        -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                  -
CD  =  =======  ========================================================-
CD  1   1-2     03                                                       -
CD                                                                       -
CD  2   7-12    0...FOR EQUILIBRIUM PROBLEMS, EDIT ATOM DENSITIES AND    -
CD                  MASSES OF ACTIVE ISOTOPES IN EACH STAGE OF EACH      -
CD                  PATH, AND FOR NON-EQUILIBRIUM PROBLEMS EDIT ATOM     -
CD                  DENSITIES AND MASSES OF ACTIVE ISOTOPES IN EACH      -
CD                  REGION ONLY ON THE AUXILIARY FILE (DEFAULT).         -
CD              1...EDIT ALSO ON THE STANDARD PRINT FILE.                -
CD                                                                       -
CD  3   13-18   0...EDIT THE CONVERSION RATIO OF EACH STAGE OF EACH      -
CD                  PATH ONLY ON THE AUXILIARY FILE (DEFAULT).           -
CD              1...EDIT ALSO ON THE STANDARD PRINT FILE.                -
CD                                                                       -
CD  4   19-24   0...EDIT THE FISSILE MASSES OF EACH STAGE OF EACH        -
CD                  PATH ONLY ON THE AUXILIARY FILE (DEFAULT).           -
CD              1...EDIT ALSO ON THE STANDARD PRINT FILE.                -
CD                                                                       -
CD  5   25-30   0...EDIT THE BURNUPS (ATOM % AND MWD/MT), AVERAGE        -
CD                  POWERS OF EACH STAGE OF EACH PATH, INSTANTANEOUS     -
CD                  STAGE TOTAL POWERS AND POWER FRACTIONS ONLY ON THE   -
CD                  AUXILIARY FILE (DEFAULT).                            -
CD              1...EDIT ALSO ON THE STANDARD PRINT FILE.                -
CD                                                                       -
```

```
CD  6   31-36   0...FOR EQUILIBRIUM PROBLEMS, PROVIDE NORMAL EDITS WHEN-
CD                  IN THE FINAL SEARCH WITH FULL EDITS (DEFAULT).     -
CD              1...FOR EQUILIBRIUM PROBLEMS, PROVIDE MINIMAL DIF3D    -
CD                  EDITS AND NO SUMMARY EXECUTION WHEN IN THE FINAL   -
CD                  SEARCH WITH FULL EDITS AT INTERMEDIATE TIME NODES. -
CD                                                                     -
CD  7   37-42   0...PROVIDE NORMAL EDITS FROM MODULE POLYFI AND CREATE -
CD                  A COMPUTER ASSOCIATES POP METAFILE FOR THE         -
CD                  PLOTTING FITS.                                     -
CD              1...SUPPRESS FITTING DATA EDITS AND DO NOT CREATE A    -
CD                  COMPUTER ASSOCIATES POP METAFILE.                  -
CD              2...SUPPRESS FITTING DATA EDITS BUT CREATE A COMPUTER  -
CD                  ASSOCIATES POP METAFILE.                           -
CD                                                                     -
CD  8   43-48   0...OMIT CALCULATION OF PEAK DISCHARGE BURNUPS         -
CD                  (DEFAULT).                                         -
CC              1...EDIT PEAK DISCHARGE BURNUPS FOR EACH PATH.         -
CD                                                                     -
CD  9   49-54   0...OMIT CALCULATION OF PEAK FAST FLUENCES (DEFAULT).  -
CD              1...EDIT PEAK FAST FLUENCES FOR EACH.                  -
CD                                                                     -
CD  10  55-60       SUMMARY FILES 1-6 CONTROL.                         -
CD                  ENTER A 6 DIGIT NUMBER ABCDEF WHERE                -
CD                                                                     -
CD                  A CONTROLS THE GENERATION OF FILE SUMRY1           -
CD                  B CONTROLS THE GENERATION OF FILE SUMRY2           -
CD                  C CONTROLS THE GENERATION OF FILE SUMRY3           -
CD                  D CONTROLS THE GENERATION OF FILE SUMRY4           -
CD                  E CONTROLS THE GENERATION OF FILE SUMRY5           -
CD                  F CONTROLS THE GENERATION OF FILE SUMRY6           -
CD                                                                     -
CD                  THE INTEGERS A, B, C, D, E, AND F SHOULD BE        -
CD                  ASSIGNED ONE OF THE FOLLOWING VALUES (LEADING      -
CD                  ZEROS ARE IRRELEVANT):                             -
CD                                                                     -
CD                  0...DO NOT CREATE THE FILE (DEFAULT)               -
CD                  1...CREATE THE FILE                                -
CD                                                                     -
CD  11  61-66       SUMMARY FILE 7 CONTROL.                            -
CD                  ENTER A 6 DIGIT NUMBER ABCDEF WHERE                -
CD                                                                     -
CD                  A CONTROLS THE GENERATION OF FILE SUMRY7           -
CD                  B CONTROLS THE GENERATION OF FILE SUMRY8           -
CD                  C CONTROLS THE GENERATION OF FILE SUMRY9           -
CD                                                                     -
CD                  DIGITS D, E, AND F ARE RESERVED FOR FUTURE         -
CD                  USE AS LATER SUMMARY FILES ARE REQUIRED.           -
CD                                                                     -
CD                  THE INTEGER A SHOULD BE ASSIGNED ONE OF THE        -
CD                  FOLLOWING VALUES (LEADING ZEROS ARE IRRELEVANT):   -
CD                                                                     -
CD                  0...DO NOT CREATE THE FILE (DEFAULT)               -
CD                  1...CREATE THE FILE                                -
CD                                                                     -
```

```
CD  12  67-72       0...NORMAL EDITS OF ALL EXTERNAL CYCLE ITERATIONS  -
CD                  1...ONLY EDIT THE EXTERNAL CYCLE ITERATION         -
CD                      RESULTS AT THE COMPLETION OF THE ITERATION     -
C                                                                      -
CN              CARD TYPE 03 CONTROLS THE EDITS WHEN IN THE FINAL      -
CN              SEARCH WITH FULL EDITS.  NOTE THAT A NON-EQUILIBRIUM   -
CN              PROBLEM IS ALWAYS CONSIDERED TO BE IN THE FINAL SEARCH.-
CN              THE CUMULATIVE EDITS ARE ALWAYS WRITTEN TO THE         -
CN              STANDARD PRINT FILE AND THE AUXILIARY PRINT FILE.      -
CN                                                                     -
CN              FOR EQUILIBRIUM PROBLEMS, THE NORMAL DIF3D EDITS AND   -
CN              SUMMARY EXECUTION ARE ALWAYS PROVIDED AT THE FIRST AND -
CN              LAST TIME NODES EVEN IF COLS. 31-36 ARE 1.  HOWEVER,   -
CN              SUMMARY EXECUTION IS OMITTED AND MINIMAL DIF3D EDITS   -
CN              ARE PROVIDED FOR THE FIRST NEUTRONICS CALCULATION AT   -
CN              THE LAST TIME NODE IF MORE THAN ONE DENSITY ITERATION  -
CN              IS SPECIFIED.                                          -
CN                                                                     -
CN              NOTE THAT COLS. 43-48 AND 49-54 MUST NOT CONTAIN A 1   -
CN              FOR PROBLEMS INVOLVING CONTROL ROD SEARCHES SINCE THE  -
CN              NUMBER OF MESH POINTS OR THE MESH COMPOSITIONS MAY      -
CN              VARY WHEN THE RODS ARE MOVED, AND THE ALGORITHM        -
CN              BEING USED ASSUMES THAT THE PEAKS CAN BE FOUND BY      -
CN              COMPARING POINT BY POINT THE BEGINNING AND END OF      -
CN              BURN STEP VALUES.                                      -
CN                                                                     -
CN              A PROBLEM WHICH IS RESTARTED USING DATASET RFILES MUST -
CN              HAVE THE SAME SENTINELS SET IN COLS. 43-48 AND 49-54   -
CN              AS WERE SET FOR THE PROBLEM WHICH PERFORMED THE WRAPUP -
CN              AND WROTE DATASET RFILES.                              -
CN                                                                     -
CN              IF COLS. 55-60 CONTAIN 101, THEN FILES SUMRY4 AND      -
CN              SUMRY6 WILL BE GENERATED AND SUMRY1, SUMRY2, SUMRY3,   -
CN              AND SUMRY5 WILL NOT BE GENERATED.  IF COLS. 61-66      -
CN              CONTAIN 100000 SUMRY7 WILL BE GENERATED, BUT SUMRY8    -
CN              AND SUMRY9 WILL NOT BE GENERATED.                      -
C                                                                      -
C----------------------------------------------------------------------


C----------------------------------------------------------------------
CR          A.DIF3D TYPE 02 CARD MODIFICATIONS (TYPE 04)               -
C                                                                      -
CL    FORMAT-----(I2,4X,3I6)                                           -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     04                                                     -
CD                                                                     -
CD  2   7-12    POINTR CONTAINER ARRAY SIZE IN FAST CORE MEMORY (FCM)   -
CD              IN REAL*8 WORDS (DEFAULT=10000).                       -
CD                                                                     -
CD  3   13-18   POINTR CONTAINER ARRAY SIZE IN EXTENDED CORE           -
CD              MEMORY (ECM) IN REAL*8 WORDS (DEFAULT=30000).          -
```

```
CD                                                                      -
CD  4   19-24   POINTR DEBUGGING EDIT.                                  -
CD              0...NO DEBUGGING PRINTOUT (DEFAULT).                    -
CD              1...DEBUGGING DUMP PRINTOUT.                            -
CD              2...DEBUGGING TRACE PRINTOUT.                           -
CD              3...BOTH DUMP AND TRACE PRINTOUT.                       -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          LOGIC FLOW MODIFICATIONS (TYPE 05)                          -
C                                                                       -
CL    FORMAT-----(I2,4X,I6)                                             -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     05                                                      -
CD                                                                      -
CD  2   7-12    0...NORMAL EXECUTION SEQUENCE                           -
CD                                                                      -
CD              1...FORCE A WRAPUP FOLLOWING EACH FUEL MANAGEMENT STEP -
CD                  FOR NON-EQUILIBRIUM PROBLEMS.  WHEN RESTARTING      -
CD                  SUCH A PROBLEM, THE LOGIC SEQUENCE WILL BE THE      -
CD                  SAME AS FOR THE CASE WHEN COLS. 7-12 ARE 0.         -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          OPTION FOR FLUX FILE SAVING ON STACK FILE (TYPE 06)         -
C                                                                       -
CL    FORMAT-----(I2,4X,I6)                                             -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     06                                                      -
CD                                                                      -
CD  2   7-12    0...NORMAL STACKING                                     -
CD                                                                      -
CD              1...DO NOT SAVE FLUX DATASETS RZFLUX, RTFLUX, AND       -
CD                  NHFLUX.                                             -
C                                                                       -
CN              REBUS-3 SAVES CCCC DATASETS NDXSRF, GEODST, LABELS,     -
CN              ZNATDN, PWDINT, RTFLUX, RZFLUX, AND NHFLUX AT EACH      -
CN              TIME NODE IN THE PROBLEM ON THE STACK FILE FOR LATER    -
CN              USE. IF THE NUMBER OF ENERGY GROUPS AND/OR SPATIAL      -
CN              MESHES IS LARGE, THE STACK FILE SIZE COULD BECOME       -
CN              PROHIBITIVELY LARGE WITH INCREASING NUMBER OF TIME      -
CN              NODES. IN THIS CASE, THE STACK FILE SIZE CAN BE         -
CN              REDUCED TO A REASONABLE SIZE BY NOT SAVING THE FLUX     -
CN              DATASETS. IF COLS. 7-12 IS 1, THE FLUX DATSETS RTFLUX,  -
CN              RZFLUX, AND NHFLUX ARE NOT SAVED ON THE STACK FILE.     -
C                                                                       -
```

```
CD  3   13-18   0 ...Do not keep DIF3D-VARIANT NHFLUX files            -
CD              1 ...Store the DIF3D-VARIANT NHFLUX files at each step -
C                                                                      -
C----------------------------------------------------------------------

CEOF
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Appendix B. Description of BCD Input Dataset A.BURN

```
C*****************************************************************
C                                                                -
C                      Latest version 11/09/05
C                                                                -
CF          A.BURN                                               -
CE          GENERAL INPUT FOR REBUS-3 FUEL CYCLE MODULES         -
C                                                                -
CN                     THIS BCD DATA SET MAY BE WRITTEN EITHER   -
CN                     IN FREE FORMAT (UNFORM=A.BURN) OR ACCORDING TO -
CN                     THE FORMATS SPECIFIED FOR EACH CARD TYPE  -
CN                     (DATASET=A.BURN).                         -
CN                                                               -
CN                     COLUMNS 1-2 MUST CONTAIN THE CARD TYPE    -
CN                     NUMBER.                                   -
CN                                                               -
CN                     A BLANK FIELD GIVES THE INDICATED DEFAULT -
CN                     VALUE.                                    -
C                                                                -
C                                                                -
CN                ***  CARD TYPE DIRECTORY  ***                  -
CN                                                               -
CN    TYPE                      CONTENTS                         -
CN    ====    ==================================================  -
CN     01     PROBLEM TITLE                                      -
CN     02     STORAGE AND CONVERGENCE CRITERIA SPECIFICATIONS     -
CN     03     GENERAL PROBLEM DEFINITION DATA                    -
CN     04     CHARGE ENRICHMENT/CRITICALITY DATA                 -
CN     05     BURNUP TEST GROUP SPECIFICATIONS                   -
CN     06     BURNUP LIMITS                                      -
CN     07     BURNUP NUMERATOR DEFINITION                        -
CN     08     BURNUP DENOMINATOR DEFINITION                      -
CN     09     ISOTOPIC CHAIN DATA                                -
CN     10     ACTIVE ISOTOPE LABEL EQUIVALENCE LIST              -
CN     11     REPETITIVE FUEL MANAGEMENT PATH DATA               -
CN     12     REACTOR CHARGE SPECIFICATIONS                      -
CN     13     FUEL FABRICATION DATA                              -
CN     14     REACTOR DISCHARGE COOLING TIMES                    -
CN     15     REACTOR DISCHARGE DESTINATION DATA                 -
CN     16     REPROCESSING PLANT SPECIFICATIONS                  -
CN     17     RECOVERY FACTOR DATA                               -
CN     18     CLASS SEPARATION DATA                              -
CN     19     CLASS 1 FABRICATION SPECIFICATIONS                 -
CN     20     CLASS 2 FABRICATION SPECIFICATIONS                 -
CN     21     EXTERNAL FEED SPECIFICATIONS                       -
CN     22     EXTERNAL FEED COMPOSITION                          -
CN     23     REPROCESSING PLANT OUPUT INITIAL COMPOSITION       -
CN     24     ACTIVE ISOTOPE DESCRIPTIONS                        -
CN     25     ACTIVE ISOTOPE DECAY CONSTANTS                     -
CN     26     ISOTOPES HAVING BURNUP DEPENDENT CROSS SECTIONS    -
CN     27     END-OF-CYCLE KEFF SEARCH DATA                      -
CN     28     AVOGADRO'S NUMBER                                  -
CN     29     SUMMARY EDITS AREA SPECIFICATIONS                  -
CN     30     SUMMARY MASS BALANCE ISOTOPE SPECIFICATIONS        -
CN     31     SUMMARY NEUTRON BALANCE ISOTOPE SPECIFICATIONS     -
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CN     32     SUMMARY MASS FLOW SPECIFICATIONS 1                          -
CN     33     SUMMARY MASS FLOW SPECIFICATIONS 2                          -
CN     34     SUMMARY MASS FLOW SPECIFICATIONS 3                          -
CN     35     GENERAL FUEL MANAGEMENT SPECIFICATIONS                      -
CN     36     GENERAL FUEL MANAGEMENT PARAMETERS                          -
CN     37     GENERAL FUEL MANAGEMENT REPETITION FACTORS                  -
CN     38     TIME DEPENDENT CONTROL ROD POSITIONS                        -
CN     39     BURNUP DEPENDENT GROUPS                                     -
CN     40     POLYNOMIAL LEAST SQUARES CRITERIA                           -
CN     41     BURNUP DEPENDENT FITTING DATA SPECIFICATIONS                -
CN     42     NON-EQUILIBRIUM DISCHARGE RECOVERY FACTOR SPECIFICATIONS    -
CN     43     NON-EQUILIBRIUM DISCHARGE REGION SPECIFICATIONS             -
CN     44     NON-EQUILIBRIUM FEED MODIFICATION SPECIFICATIONS            -
CN     45     FUEL MANAGEMENT GROUP SPECIFICATIONS                        -
CN     46     USER DEFINED CONVERSION RATIO NUCLIDES                      -
CN     47     VARIABLE TIME STEP SPECIFICATION                            -
C                                                                         -
C*************************************************************************


C-------------------------------------------------------------------------
CR          PROBLEM TITLE (TYPE 01)                                       -
C                                                                         -
CL    FORMAT-----(I2,4X,11A6)                                             -
C                                                                         -
CD     COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                   -
CD     =======  ========================================================-
CD      1-2     01                                                        -
CD                                                                        -
CD      7-72    ANY ALPHANUMERIC CHARACTERS.                              -
C                                                                         -
CN              AS MANY TYPE 01 CARDS MAY BE USED AS DESIRED.             -
C                                                                         -
C-------------------------------------------------------------------------


C-------------------------------------------------------------------------
CR          STORAGE AND CONVERGENCE CRITERIA SPECIFICATIONS (TYPE 02)     -
C                                                                         -
CL    FORMAT-----(I2,4X,3I6,3E12.5,2I6)                                   -
C                                                                         -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                   -
CD  =  =======  ========================================================-
CD  1   1-2     02                                                        -
CD                                                                        -
CD  2   7-12    POINTR AND COMMON BLOCK DEBUGGING EDITS.                   -
CD             -1...COMMON BLOCKS /SINGLE/ AND /POINTS/ PRINTOUT.         -
CD              0...NO DEBUGGING PRINTOUT (DEFAULT).                      -
CD              1...POINTER DEBUGGING DUMP AND COMMON BLOCKS PRINTOUT.    -
CD              2...POINTER DEBUGGING TRACE AND COMMON BLOCKS PRINTOUT.   -
CD              3...FULL DEBUGGING PRINTOUT (TRACE + DUMP + COMMON        -
CD                                    BLOCKS PRINTOUT).                   -
CD                                                                        -
CD  3   13-18   POINTR CONTAINER ARRAY SIZE IN SCM IN REAL*8 WORDS.       -
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CD              (DEFAULT=20000).                                        -
CD                                                                      -
CD  4   19-24   POINTR CONTAINER ARRAY SIZE IN LC IN REAL*8 WORDS.      -
CD              (DEFAULT=0).                                            -
CD                                                                      -
CD  5   25-36   CONVERGENCE CRITERION, EPSN: MAXIMUM ALLOWABLE RELATIVE-
CD              ERROR IN ANY ISOTOPE REGION DENSITY. FOR CONVERGENCE    -
CD              OF REGION-DENSITY ITERATIONS (DEFAULT=0.001).           -
CD                                                                      -
CD  6   37-48   CONVERGENCE CRITERION, EPSC: MAXIMUM ALLOWABLE RELATIVE-
CD              ERROR IN ANY ISOTOPE STAGE DENSITY. FOR CONVERGENCE OF -
CD              CYCLIC MODE ITERATIONS (DEFAULT=0.001).                 -
CD                                                                      -
CD  7   49-60   CONVERGENCE CRITERION, EPSE: MAXIMUM ALLOWABLE RELATIVE-
CD              ERROR IN ANY ISOTOPE CHARGE DENSITY. FOR CONVERGENCE    -
CD              OF UNCONSTRAINED EQUILIBRIUM MODE (DEFAULT=0.0001).     -
CD                                                                      -
CD  8   61-66   MAXIMUM NUMBER OF REGION-DENSITY ITERATIONS AT A TIME   -
CD              NODE, LMAX. RECOMMENDED VALUE IS 1. LMAX IS SET TO 5    -
CD              IF INPUT VALUE IS GREATER THAN 5. IF LMAX=N, UP TO N    -
CD              NEUTRONICS SOLUTIONS WILL BE OBTAINED AT EACH TIME      -
CD              NODE (SEE CARD TYPE 03). LMAX=0 MEANS NO AVERAGING OF   -
CD              THE BURN MATRIX WILL BE DONE. THIS VALUE SHOULD NOT BE  -
CD              USED FOR EQUILIBRIUM PROBLEMS. IF NO TYPE 02 CARD IS    -
CD              SUPPLIED, OR IF THIS IS AN EQUILIBRIUM PROBLEM, A       -
CD              DEFAULT VALUE OF 1 WILL BE USED.                        -
CD                                                                      -
CD  9   67-72   MAXIMUM NUMBER OF CYCLIC MODE ITERATIONS, MMAX.         -
CD              (DEFAULT=1).                                            -
C                                                                       -
CN              FOR NONEQUILIBRIUM PROBLEMS, SET EPSC=EPSE=1.000.       -
CN              PROBLEMS INVOLVING HIGH FUEL BURNUP (GREATER THAN       -
CN              ABOUT 20 ATOM PER CENT) SHOULD USE 2 CYCLIC MODE        -
CN              ITERATIONS (COLS 67-72).  VERY HIGH DISCHARGE BURNUP    -
CN              (GREATER THAN ABOUT 50 ATOM PER CENT) MAY REQUIRE MORE  -
CN              THAN 2 CYCLIC MODE ITERATIONS.                          -
C                                                                       -
CN              IF COLS. 61-66 ARE NEGATIVE, NO REGION DENSITY          -
CN              EXTRAPOLATIONS WILL BE PERFORMED.  NORMALLY, THE        -
CN              REGION DENSITIES ARE EXTRAPOLATED AFTER THE 2ND AND     -
CN              4TH END OF BURN STEP NEUTRONICS HAVE BEEN PERFORMED     -
CN              TO ATTEMPT TO ACCELERATE THE PROBLEM.  HOWEVER, IT HAS  -
CN              BEEN OBSERVED THAT FOR SOME PROBLEMS, THE EXTRAPOLATION-
CN              PROCEDURE OUTLINED IN ANL-7721 ON PP. 51-52 LEADS TO    -
CN              ERRONEOUS VALUES FOR THE REGION DENSITIES.  IN FACT,    -
CN              NEGATIVE REGION DENSITIES HAVE BEEN GENERATED IN SOME   -
CN              PROBLEMS.  SETTING COLS. 61-66 TO THE NEGATIVE NUMBER   -
CN              OF REGION-DENSITY ITERATIONS TO BE PERFORMED WILL        -
CN              AVOID THESE PROBLEMS.                                   -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
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CR          GENERAL PROBLEM DEFINITION DATA (TYPE 03)                    -
C                                                                        -
CL    FORMAT-----(I2,4X,I6,4E12.5,2I6)                                   -
C                                                                        -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                  -
CD  =  =======  ========================================================-
CD  1   1-2     03                                                       -
CD                                                                       -
CD  2   7-12    NUMBER OF PREVIOUS BURN CYCLES.                          -
CD                                                                       -
CD  3   13-24   SHUTDOWN TIME BETWEEN BURN CYCLES (IN DAYS).            -
CD              (NONEQUILIBRIUM PROBLEMS ONLY).                          -
CD                                                                       -
CD  4   25-36   TIME AT WHICH PROBLEM BEGINS (IN DAYS).                  -
CD                                                                       -
CD  5   37-48   INITIAL TOTAL BURN CYCLE TIME GUESS (IN DAYS).           -
CD                                                                       -
CD  6   49-60   CONVERGENCE CRITERION, EPSG: ACTUAL ERROR ALLOWABLE     -
CD              IN BURNUP (SEE CARD TYPE 06 AND NOTE BELOW).             -
CD              (DEFAULT=0.001).                                         -
CD                                                                       -
CD  7   61-66   NUMBER OF SUBINTERVALS INTO WHICH THE TOTAL BURN CYCLE -
CD              TIME IS TO BE DIVIDED.                                   -
CD                                                                       -
CD  8   67-72   NUMBER OF FUEL MANAGEMENT OPERATIONS, FOR               -
CD              NONEQUILIBRIUM PROBLEMS ONLY. THIS VALUE IS 1 LESS       -
CD              THAN THE TOTAL NUMBER OF BURN CYCLES WHICH WILL BE       -
CD              COMPUTED.                                                -
C                                                                        -
CN              THE DATA CARDS OF A.BURN MAY BE DIVIDED INTO THE         -
CN              FOLLOWING FUNCTIONAL GROUPS:                             -
CN                                                  CARD TYPES           -
CN                      FUNCTION                 REQUIRED      OPTIONAL  -
CN              ========================  ===============  ===========-
CN              BASIC (NONEQUIL.) PROBLEM  03,09,11(35),24  01,02,10,25-
CN                                                                       -
CN              CHARGE ENRICHMENT SEARCH   04                            -
CN              + REQUIRED EXTERNAL CYCLE  12,13,18-22         --        -
CN                                                                       -
CN              BURNUP LIMITS              06               05,07,08    -
CN                                                                       -
CN              REPROCESSING PLANTS        15,16,17         14,23       -
CN                                                                       -
CN              IF THE FUEL MANAGEMENT IS SPECIFIED USING THE TYPE 35    -
CN              CARDS RATHER THAN THE TYPE 11 CARDS, CARD TYPES          -
CN              14, 15, 16, 17, AND 23 SHOULD NOT BE SUPPLIED.           -
CN                                                                       -
CN              THE TWO BASIC TYPES OF PROBLEMS WHICH MAY BE RUN ARE     -
CN              EQUILIBRIUM AND NONEQUILIBRIUM. AN EQUILIBRIUM PROBLEM -
CN              IS DEFINED AS ONE IN WHICH THE USER WISHES TO FIND THE -
CN              OPERATING CONDITIONS OF THE SPECIFIED REACTOR AFTER AN -
CN              INFINITE NUMBER OF BURN/DISCHARGE/REFUEL STEPS WITH      -
CN              THE CONDITIONS AND CONSTRAINTS AS SUPPLIED. SUCH         -
CN              PROBLEMS REQUIRE THE BASIC PROBLEM CARDS, THE CHARGE     -
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CN              ENRICHMENT SEARCH AND EXTERNAL CYCLE CARDS, AND THE    -
CN              SPECIFICATION OF AT LEAST ONE BURNUP LIMIT.            -
CN              OPTIONALLY, ONE MAY INCLUDE REPROCESSING PLANTS IN THE -
CN              EXTERNAL CYCLE. A NONEQUILIBRIUM PROBLEM, ON THE OTHER -
CN              HAND, IS ONE IN WHICH THE BURN/REFUEL STEPS ARE        -
CN              EXPLICITLY COMPUTED IN SUCCESSION USING THE SUPPLIED   -
CN              PARAMETERS AND CONSTRAINTS. SUCH PROBLEMS REQUIRE ONLY -
CN              THE BASIC PROBLEM CARD TYPES LISTED ABOVE. OPTIONALLY, -
CN              ONE MAY SPECIFY AN ENRICHMENT SEARCH BY INCLUDING CARD -
CN              TYPE 04 AND THE REQUIRED EXTERNAL CYCLE CARDS. IF SUCH -
CN              A SEARCH IS SPECIFIED, ONE MAY ALSO SPECIFY DESIRED    -
CN              BURNUP LIMITS BY INCLUDING THE APPROPRIATE CARDS.      -
CN                                                                     -
CN              THE TOTAL BURN CYCLE TIME MAY BE DIVIDED INTO A NUMBER -
CN              OF EQUAL SUBINTERVALS, AS GIVEN IN COLS. 61-66 OF THIS -
CN              CARD. FLUX DISTRIBUTIONS WILL BE COMPUTED AT TIME ZERO -
CN              AND AT THE END OF EACH OF THESE SUBINTERVALS. EACH     -
CN              SUCH POINT IS CALLED A TIME NODE. A PROBLEM WITH N     -
CN              SUBINTERVALS THUS HAS N+1 TIME NODES. IF CONTROL       -
CN              MATERIALS ARE PRESENT, THE APPROPRIATE CONTROL SEARCHES-
CN              MAY BE CARRIED OUT TO MAINTAIN A PRESCRIBED KEFF AT    -
CN              EACH OF THESE TIME NODES. (SEE CARD TYPES 21, 22       -
CN              AND 23 OF DATA SET A.NIP3).                            -
CN                                                                     -
CN              FOR EQUILIBRIUM PROBLEMS, A MAXIMUM OF FOUR            -
CN              SUBINTERVALS IS ALLOWED. THERE IS NO LIMIT FOR         -
CN              NONEQUILIBRIUM PROBLEMS.                               -
CN                                                                     -
CN              NOTE: IF COLS. 49-60 ARE NON-NEGATIVE, THE BURNUP WILL -
CN              BE DEFINED AS THE RATIO OF FISSIONABLE ATOMS DESTROYED -
CN              BY FISSION IN THE DISCHARGED FUEL TO THE TOTAL         -
CN              FISSIONABLE ATOMS INITIALLY PRESENT IN THE FUEL.  IF   -
CN              COLS. 49-60 ARE NEGATIVE, THE BURNUP WILL BE DEFINED   -
CN              AS THE RATIO OF FISSIONABLE ATOMS DESTROYED BY ALL     -
CN              PROCESSES IN THE DISCHARGED FUEL TO THE TOTAL          -
CN              FISSIONABLE ATOMS INITIALLY PRESENT IN THE FUEL, AND   -
CN              THE ABSOLUTE VALUE OF COLS. 49-60 WILL BE USED FOR     -
CN              EPSG.  FISSIONABLE ISOTOPES ARE THOSE ACTIVE ISOTOPES  -
CN              WHICH APPEAR ON A CARD TYPE 09 WITH A 2 IN COLS. 13-18.-
C                                                                      -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          CHARGE ENRICHMENT/CRITICALITY DATA (TYPE 04)               -
C                                                                      -
CL    FORMAT-----(I2,10X,5E12.5)                                       -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     04                                                     -
CD                                                                     -
CD  2   13-24   DESIRED UNPOISONED KEFF(0).                            -
CD                                                                     -
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CD  3    25-36   CONVERGENCE CRITERION, EPSF: RELATIVE ERROR ALLOWABLE  -
CD               IN KEFF(0) DURING CHARGE ENRICHMENT SEARCHES           -
CD               (DEFAULT=0.001).                                       -
CD                                                                      -
CD  4    37-48   FRACTION OF TOTAL BURN TIME AT WHICH KEFF(0) IS TO BE  -
CD               REACHED. THIS MUST BE ONE OF THE END POINTS OF A       -
CD               SUBINTERVAL OF THE BURN STEP, I.E. A TIME NODE.        -
CD                                                                      -
CD  5    49-60   INITIAL VALUE FOR THE CHARGE ENRICHMENT                 -
CD               SEARCH PARAMETER X.                                    -
CD                                                                      -
CD  6    61-72   SECOND VALUE FOR THE CHARGE ENRICHMENT                 -
CD               SEARCH PARAMETER X. (DEFAULT=INITIAL VALUE FROM        -
CD               COLS.49-60 PLUS 0.1).                                  -
C                                                                       -
CN               THE ENRICHMENT OF A BATCH OF FRESH FUEL IDENTIFIED     -
CN               AS CHARGE TYPE M IS ADJUSTED ACCORDING TO THE FORMULA  -
CN                         E(M)=E(M)(0)(1+(X-1.)*DELTA(M)),             -
CN               WHERE X IS THE CHARGE ENRICHMENT SEARCH PARAMETER      -
CN               WHOSE INITIAL VALUE IS GIVEN IN COLS. 49-60.           -
CN               THE E(M)(0) AND DELTA(M) FOR EACH CHARGE TYPE ARE      -
CN               SPECIFIED ON CARD TYPE 12. RESULTING VALUE OF E(M)     -
CN               MUST ALWAYS LIE BETWEEN 0 AND 1.                       -
CN                                                                      -
CN               IF CARD TYPE 04 IS SUPPLIED, ALL "REQUIRED EXTERNAL    -
CN               CYCLE" CARDS MUST BE INCLUDED (SEE DISCUSSION IN CARD  -
CN               TYPE 03).                                              -
CN                                                                      -
CN               IN THE FOLLOWING CARDS, A "LABEL" WILL BE IDENTIFIED   -
CN               FROM THE CARD TYPE (E.G., CARD TYPE 21 INDICATES THAT  -
CN               EXTERNAL FEED DATA ARE TO FOLLOW). A LABEL IS DEFINED  -
CN               AS A SIX-CHARACTER IDENTIFIER THAT REFERENCES THE       -
CN               SPECIFIC OPERATIONS OR DATA THAT FOLLOW. FOR EXAMPLE,   -
CN               A "PATH" LABEL DEFINES A SPECIFIC SEQUENCE OF SPATIAL   -
CN               POSITIONS AND MOTIONS OF A "CHARGE" IN THE REACTOR      -
CN               AS LISTED ON THE CARD.                                 -
CN                                                                      -
CN               THE ISOTOPE LABELING SYSTEM ALLOWS DIFFERENT LIBRARY   -
CN               LABELS (I.E., DIFFERENT MICROSCOPIC CROSS SECTIONS) TO -
CN               BE USED IN DIFFERENT FUEL BATCHES. THE INTERNAL, OR    -
CN               RUN-TIME, LABELS FOR "ACTIVE" ISOTOPES (THOSE THAT ARE -
CN               INCLUDED IN THE TRANSMUTATION MATRIX) ARE DEFINED      -
CN               IN THE SPECIFICATION OF THE ISOTOPIC CHAIN (CARD TYPE   -
CN               09). THESE RUN-TIME LABELS MAY COINCIDE WITH THE       -
CN               LIBRARY LABELS FOR ALL MATERIALS, IN WHICH CASE NO     -
CN               FUTHER INPUT IS REQUIRED. THE USER MAY, HOWEVER,       -
CN               SPECIFY (SEE CARD TYPE 10) THAT A LIBRARY ISOTOPE      -
CN               LABEL (WHICH DEFINES APPROPRIATE CROSS SECTIONS FOR    -
CN               SOME FUEL BATCH) IS EQUIVALENT TO ONE OF THOSE         -
CN               SPECIFIED ON CARD TYPE 09. ALL LIBRARY ISOTOPES THAT   -
CN               ARE EQUIVALENCED TO ONE OF THESE RUN-TIME LABELS ARE   -
CN               CONSIDERED IDENTICAL IN THE EXTERNAL CYCLE.            -
CN               APPROPRIATE MICROSCOPIC CROSS SECTIONS FOR THE FRESH   -
CN               CHARGE BATCHES ARE SELECTED THROUGH THE FUEL            -
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CN              FABRICATION DATA ON CARD TYPE 13. ACTIVE ISOTOPE       -
CN              LABELS APPEARING ON CARD TYPES OTHER THAN 10 OR 13     -
CN              MUST BE THOSE THAT APPEAR IN COLS. 7-12 OF THE TYPE    -
CN              09 CARDS OR VIA THE PRESTORED BURNUP CHAINS (SEE CARD  -
CN              TYPE 09).                                              -
C                                                                      -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          BURNUP TEST GROUP SPECIFICATIONS (TYPE 05)                 -
C                                                                      -
CL    FORMAT-----(I2,4X,11A6)                                          -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     05                                                     -
CD                                                                     -
CD  2   7-12    LABEL OF BURNUP TEST GROUP (REPEATED ON ADDITIONAL      -
CD              CARDS).                                                -
CD                                                                     -
CD  3   13-18   PATH LABEL (SEE CARD TYPE 11 OR CARD TYPE 35) TO BE    -
CD              INCLUDED IN TEST GROUP. SEE NOTE FOLLOWING CARD TYPE 06-
CD                                                                     -
CD  4   19-24   PATH LABEL (SEE CARD TYPE 11 OR CARD TYPE 35) TO BE    -
CD              INCLUDED IN TEST GROUP. SEE NOTE FOLLOWING CARD TYPE 06-
CD                                                                     -
CD  5   25-30   PATH LABEL (SEE CARD TYPE 11 OR CARD TYPE 35) TO BE    -
CD              INCLUDED IN TEST GROUP. SEE NOTE FOLLOWING CARD TYPE 06-
CD                                                                     -
CD  6   31-36   PATH LABEL (SEE CARD TYPE 11 OR CARD TYPE 35) TO BE    -
CD              INCLUDED IN TEST GROUP. SEE NOTE FOLLOWING CARD TYPE 06-
CD                                                                     -
CD  7   37-42   PATH LABEL (SEE CARD TYPE 11 OR CARD TYPE 35) TO BE    -
CD              INCLUDED IN TEST GROUP. SEE NOTE FOLLOWING CARD TYPE 06-
CD                                                                     -
CD  8   43-48   PATH LABEL (SEE CARD TYPE 11 OR CARD TYPE 35) TO BE    -
CD              INCLUDED IN TEST GROUP. SEE NOTE FOLLOWING CARD TYPE 06-
CD                                                                     -
CD  9   49-54   PATH LABEL (SEE CARD TYPE 11 OR CARD TYPE 35) TO BE    -
CD              INCLUDED IN TEST GROUP. SEE NOTE FOLLOWING CARD TYPE 06-
CD                                                                     -
CD  10  55-60   PATH LABEL (SEE CARD TYPE 11 OR CARD TYPE 35) TO BE    -
CD              INCLUDED IN TEST GROUP. SEE NOTE FOLLOWING CARD TYPE 06-
CD                                                                     -
CD  11  61-66   PATH LABEL (SEE CARD TYPE 11 OR CARD TYPE 35) TO BE    -
CD              INCLUDED IN TEST GROUP. SEE NOTE FOLLOWING CARD TYPE 06-
CD                                                                     -
CD  12  67-72   PATH LABEL (SEE CARD TYPE 11 OR CARD TYPE 35) TO BE    -
CD              INCLUDED IN TEST GROUP. SEE NOTE FOLLOWING CARD TYPE 06-
C                                                                      -
CN              USERS SHOULD NORMALLY ORDER THE PATH LABELS IN COLS.    -
CN              13-18 SO THAT THEY AGREE WITH THE ORDER SPECIFIED ON    -
CN              THE TYPE 11 OR 35 CARDS TO AVOID AN OBSCURE CODING BUG -
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CN              WHICH OCCURS FOR CERTAIN INPUT SITUATIONS.              -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          BURNUP LIMITS (TYPE 06)                                     -
C                                                                       -
CL    FORMAT-----(I2,10X,3(A6,E12.5))                                   -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     06                                                      -
CD                                                                      -
CD  2   13-18   TEST GROUP OR PATH LABEL.                               -
CD                                                                      -
CD  3   19-30   DISCHARGE BURNUP LIMIT (AS DECIMAL FRACTION).           -
CD                                                                      -
CD  4   31-36   TEST GROUP OR PATH LABEL.                               -
CD                                                                      -
CD  5   37-48   DISCHARGE BURNUP LIMIT (AS DECIMAL FRACTION).           -
CD                                                                      -
CD  6   49-54   TEST GROUP OR PATH LABEL.                               -
CD                                                                      -
CD  7   55-66   DISCHARGE BURNUP LIMIT (AS DECIMAL FRACTION).           -
C                                                                       -
CN                                                                      -
CN              NOTE THAT TYPE 06 CARDS MUST NOT BE SUPPLIED IF THE     -
CN              PROBLEM DOES NOT IN FACT REQUIRE A BURNUP SEARCH.       -
CN              TYPICALLY, NONEQUILIBRIUM PROBLEMS SHOULD NOT HAVE      -
CN              TYPE 06 CARDS.                                          -
CN                                                                      -
CN              EACH BURNUP LIMIT REFERS TO THE RATIO OF THE TOTAL      -
CN              NUMBER OF ATOMS DESTROYED (ACCORDING TO THE SIGN OF     -
CN              THE DATA IN COLS. 49-60 ON CARD TYPE 03) IN THE         -
CN              DISCHARGED FUEL TO THE TOTAL ATOMS INITIALLY PRESENT    -
CN              IN THE FUEL.                                            -
CN              UNLESS SPECIFIED OTHERWISE (SEE CARD TYPES 07 AND 08),  -
CN              THE NUMERATOR OF THIS RATIO INCLUDES REACTIONS FOR ALL  -
CN              FISSIONABLE ISOTOPES OCCURING OVER THE BURN CYCLE, AND  -
CN              THE DENOMINATOR INCLUDES ALL FISSIONABLE ATOMS PRESENT  -
CN              AT THE START OF THE BURN CYCLE.                         -
CN                                                                      -
CN              A BURNUP LIMIT MAY BE SPECIFIED FOR A TEST GROUP,       -
CN              CONSISTING OF A COLLECTION OF SEVERAL PATHS AS          -
CN              SPECIFIED ON TYPE 05 CARDS, AND/OR A SINGLE PATH. FOR   -
CN              TEST GROUPS A SINGLE AVERAGE BURNUP IS COMPUTED WHILE   -
CN              FOR A PATH LABEL A SEPARATE BURNUP IS COMPUTED FOR      -
CN              EACH MATERIAL TYPE TO WHICH THAT PATH APPLIES. IF NO    -
CN              BURNUP LIMIT IS GIVEN, NO BURNUP TEST IS MADE FOR THAT  -
CN              PATH OR TEST GROUP.                                     -
CN                                                                      -
CN              WE DEFINE THE RELATIVE BURNUP ERROR AS THE VALUE OF     -
CN              THE DIFFERENCE BETWEEN ALLOWABLE AND ACHIEVED BURNUP    -
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CN              RELATIVE TO THE ALLOWABLE BURNUP. THAT PATH OR TEST    -
CN              GROUP WHICH COMES CLOSEST TO OR MOST EXCEEDS ITS       -
CN              BURNUP LIMIT IS THE ONE WHICH HAS THE SMALLEST         -
CN              RELATIVE BURNUP, I.E., THE MINIMUM OF                  -
CN                 (BURNUP ALLOWED - BURNUP ACHIEVED)/BURNUP ALLOWED   -
CN              OVER ALL PATHS OR TEST GROUPS. DENOTING THIS LIMITING  -
CN              PATH OR TEST GROUP BY M, THE TOTAL BURN CYCLE TIME     -
CN              WILL BE ADJUSTED UNTIL THE ACTUAL BURNUP OF M IS       -
CN              WITHIN PLUS OR MINUS EPSG OF THE ALLOWABLE BURNUP      -
CN              LIMIT SPECIFIED ON THE TYPE 06 CARD, I.E., UNTIL       -
CN              (BURNUP ALLOWED-BURNUP ACHIEVED)=0 PLUS OR MINUS EPSG. -
CN              THIS WILL GIVE THE LONGEST BURN CYCLE TIME FOR WHICH   -
CN              ALL PATHS AND/OR TEST GROUPS REMAIN WITHIN THEIR       -
CN              RESPECTIVE BURNUP LIMITS.                              -
CN                                                                     -
CN              SETTING EPSG (COLS. 49-60 ON CARD TYPE 03) TO A LARGE  -
CN              NUMBER WILL ALLOW THE BURNUPS TO BE COMPUTED BUT WILL  -
CN              PREVENT ANY ADJUSTMENT OF THE BURN CYCLE TIME.         -
C                                                                      -
C----------------------------------------------------------------------


C----------------------------------------------------------------------
CR          BURNUP NUMERATOR DEFINITION (TYPE 07)                      -
C                                                                      -
CL    FORMAT-----(I2,4X,11A6)                                          -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     07                                                     -
CD                                                                     -
CD  2   7-12    TEST GROUP OR PATH LABEL (REPEATED ON ADDITIONAL        -
CD              CARDS, IF NECESSARY).                                  -
CD                                                                     -
CD  3   13-18   LABEL OF FISSIONABLE ISOTOPE TO BE INCLUDED IN         -
CD              NUMERATOR OF BURNUP EXPRESSION FOR THE SPECIFIED       -
CD              TEST GROUP OR PATH. (NOTE: THIS IS A LABEL FROM        -
CD              COLS. 7-12 OF THE ACTIVE CHAIN SPECIFIED ON CARD       -
CD              TYPE 09 OR IN A PRESTORED BURNUP CHAIN.)               -
CD                                                                     -
CD  4   19-24   LABEL OF FISSIONABLE ISOTOPE TO BE INCLUDED IN         -
CD              NUMERATOR OF BURNUP EXPRESSION FOR THE SPECIFIED       -
CD              TEST GROUP OR PATH. (NOTE: THIS IS A LABEL FROM        -
CD              COLS. 7-12 OF THE ACTIVE CHAIN SPECIFIED ON CARD       -
CD              TYPE 09 OR IN A PRESTORED BURNUP CHAIN.)               -
CD                                                                     -
CD  5   25-30   LABEL OF FISSIONABLE ISOTOPE TO BE INCLUDED IN         -
CD              NUMERATOR OF BURNUP EXPRESSION FOR THE SPECIFIED       -
CD              TEST GROUP OR PATH. (NOTE: THIS IS A LABEL FROM        -
CD              COLS. 7-12 OF THE ACTIVE CHAIN SPECIFIED ON CARD       -
CD              TYPE 09 OR IN A PRESTORED BURNUP CHAIN.)               -
CD                                                                     -
CD  6   31-36   LABEL OF FISSIONABLE ISOTOPE TO BE INCLUDED IN         -
CD              NUMERATOR OF BURNUP EXPRESSION FOR THE SPECIFIED       -
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CD              TEST GROUP OR PATH. (NOTE: THIS IS A LABEL FROM         -
CD              COLS. 7-12 OF THE ACTIVE CHAIN SPECIFIED ON CARD        -
CD              TYPE 09 OR IN A PRESTORED BURNUP CHAIN.)                -
CD                                                                      -
CD  7   37-42   LABEL OF FISSIONABLE ISOTOPE TO BE INCLUDED IN          -
CD              NUMERATOR OF BURNUP EXPRESSION FOR THE SPECIFIED        -
CD              TEST GROUP OR PATH. (NOTE: THIS IS A LABEL FROM         -
CD              COLS. 7-12 OF THE ACTIVE CHAIN SPECIFIED ON CARD        -
CD              TYPE 09 OR IN A PRESTORED BURNUP CHAIN.)                -
CD                                                                      -
CD  8   43-48   LABEL OF FISSIONABLE ISOTOPE TO BE INCLUDED IN          -
CD              NUMERATOR OF BURNUP EXPRESSION FOR THE SPECIFIED        -
CD              TEST GROUP OR PATH. (NOTE: THIS IS A LABEL FROM         -
CD              COLS. 7-12 OF THE ACTIVE CHAIN SPECIFIED ON CARD        -
CD              TYPE 09 OR IN A PRESTORED BURNUP CHAIN.)                -
CD                                                                      -
CD  9   49-54   LABEL OF FISSIONABLE ISOTOPE TO BE INCLUDED IN          -
CD              NUMERATOR OF BURNUP EXPRESSION FOR THE SPECIFIED        -
CD              TEST GROUP OR PATH. (NOTE: THIS IS A LABEL FROM         -
CD              COLS. 7-12 OF THE ACTIVE CHAIN SPECIFIED ON CARD        -
CD              TYPE 09 OR IN A PRESTORED BURNUP CHAIN.)                -
CD                                                                      -
CD  10  55-60   LABEL OF FISSIONABLE ISOTOPE TO BE INCLUDED IN          -
CD              NUMERATOR OF BURNUP EXPRESSION FOR THE SPECIFIED        -
CD              TEST GROUP OR PATH. (NOTE: THIS IS A LABEL FROM         -
CD              COLS. 7-12 OF THE ACTIVE CHAIN SPECIFIED ON CARD        -
CD              TYPE 09 OR IN A PRESTORED BURNUP CHAIN.)                -
CD                                                                      -
CD  11  61-66   LABEL OF FISSIONABLE ISOTOPE TO BE INCLUDED IN          -
CD              NUMERATOR OF BURNUP EXPRESSION FOR THE SPECIFIED        -
CD              TEST GROUP OR PATH. (NOTE: THIS IS A LABEL FROM         -
CD              COLS. 7-12 OF THE ACTIVE CHAIN SPECIFIED ON CARD        -
CD              TYPE 09 OR IN A PRESTORED BURNUP CHAIN.)                -
CD                                                                      -
CD  12  67-72   LABEL OF FISSIONABLE ISOTOPE TO BE INCLUDED IN          -
CD              NUMERATOR OF BURNUP EXPRESSION FOR THE SPECIFIED        -
CD              TEST GROUP OR PATH. (NOTE: THIS IS A LABEL FROM         -
CD              COLS. 7-12 OF THE ACTIVE CHAIN SPECIFIED ON CARD        -
CD              TYPE 09 OR IN A PRESTORED BURNUP CHAIN.)                -
C                                                                       -
CN              IF THIS CARD IS PRESENT, ONLY FISSION REACTIONS OF      -
CN              ISOTOPES APPEARING IN THIS LIST CONTRIBUTE TOWARD       -
CN              THE CALCULATION OF THE BURNUP NUMERATOR OF THE TEST     -
CN              GROUP OR PATH SPECIFIED IN COLS. 7-12.                  -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          BURNUP DENOMINATOR DEFINITION (TYPE 08)                     -
C                                                                       -
CL    FORMAT-----(I2,4X,11A6)                                           -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
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CD  =  =======  ========================================================-
CD  1   1-2     08                                                      -
CD                                                                      -
CD  2   7-12    TEST GROUP OR PATH LABEL (REPEATED ON ADDITIONAL         -
CD              CARDS, IF NECESSARY).                                   -
CD                                                                      -
CD  3   13-18   LABEL OF ACTIVE ISOTOPE TO BE INCLUDED IN DENOMINATOR   -
CD              OF BURNUP EXPRESSION FOR THE SPECIFIED TEST GROUP OR     -
CD              PATH. (NOTE: THIS IS A LABEL FROM COLS. 7-12 OF THE      -
CD              ACTIVE CHAIN SPECIFIED ON CARD TYPE 09 OR IN A           -
CD              PRESTORED BURNUP CHAIN.)                                -
CD                                                                      -
CD  4   19-24   LABEL OF ACTIVE ISOTOPE TO BE INCLUDED IN DENOMINATOR   -
CD              OF BURNUP EXPRESSION FOR THE SPECIFIED TEST GROUP OR     -
CD              PATH. (NOTE: THIS IS A LABEL FROM COLS. 7-12 OF THE      -
CD              ACTIVE CHAIN SPECIFIED ON CARD TYPE 09 OR IN A           -
CD              PRESTORED BURNUP CHAIN.)                                -
CD                                                                      -
CD  5   25-30   LABEL OF ACTIVE ISOTOPE TO BE INCLUDED IN DENOMINATOR   -
CD              OF BURNUP EXPRESSION FOR THE SPECIFIED TEST GROUP OR     -
CD              PATH. (NOTE: THIS IS A LABEL FROM COLS. 7-12 OF THE      -
CD              ACTIVE CHAIN SPECIFIED ON CARD TYPE 09 OR IN A           -
CD              PRESTORED BURNUP CHAIN.)                                -
CD                                                                      -
CD  6   31-36   LABEL OF ACTIVE ISOTOPE TO BE INCLUDED IN DENOMINATOR   -
CD              OF BURNUP EXPRESSION FOR THE SPECIFIED TEST GROUP OR     -
CD              PATH. (NOTE: THIS IS A LABEL FROM COLS. 7-12 OF THE      -
CD              ACTIVE CHAIN SPECIFIED ON CARD TYPE 09 OR IN A           -
CD              PRESTORED BURNUP CHAIN.)                                -
CD                                                                      -
CD  7   37-42   LABEL OF ACTIVE ISOTOPE TO BE INCLUDED IN DENOMINATOR   -
CD              OF BURNUP EXPRESSION FOR THE SPECIFIED TEST GROUP OR     -
CD              PATH. (NOTE: THIS IS A LABEL FROM COLS. 7-12 OF THE      -
CD              ACTIVE CHAIN SPECIFIED ON CARD TYPE 09 OR IN A           -
CD              PRESTORED BURNUP CHAIN.)                                -
CD                                                                      -
CD  8   43-48   LABEL OF ACTIVE ISOTOPE TO BE INCLUDED IN DENOMINATOR   -
CD              OF BURNUP EXPRESSION FOR THE SPECIFIED TEST GROUP OR     -
CD              PATH. (NOTE: THIS IS A LABEL FROM COLS. 7-12 OF THE      -
CD              ACTIVE CHAIN SPECIFIED ON CARD TYPE 09 OR IN A           -
CD              PRESTORED BURNUP CHAIN.)                                -
CD                                                                      -
CD  9   49-54   LABEL OF ACTIVE ISOTOPE TO BE INCLUDED IN DENOMINATOR   -
CD              OF BURNUP EXPRESSION FOR THE SPECIFIED TEST GROUP OR     -
CD              PATH. (NOTE: THIS IS A LABEL FROM COLS. 7-12 OF THE      -
CD              ACTIVE CHAIN SPECIFIED ON CARD TYPE 09 OR IN A           -
CD              PRESTORED BURNUP CHAIN.)                                -
CD                                                                      -
CD  10  55-60   LABEL OF ACTIVE ISOTOPE TO BE INCLUDED IN DENOMINATOR   -
CD              OF BURNUP EXPRESSION FOR THE SPECIFIED TEST GROUP OR     -
CD              PATH. (NOTE: THIS IS A LABEL FROM COLS. 7-12 OF THE      -
CD              ACTIVE CHAIN SPECIFIED ON CARD TYPE 09 OR IN A           -
CD              PRESTORED BURNUP CHAIN.)                                -
CD                                                                      -
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CD  11  61-66   LABEL OF ACTIVE ISOTOPE TO BE INCLUDED IN DENOMINATOR  -
CD              OF BURNUP EXPRESSION FOR THE SPECIFIED TEST GROUP OR   -
CD              PATH. (NOTE: THIS IS A LABEL FROM COLS. 7-12 OF THE    -
CD              ACTIVE CHAIN SPECIFIED ON CARD TYPE 09 OR IN A         -
CD              PRESTORED BURNUP CHAIN.)                               -
CD                                                                     -
CD  12  67-72   LABEL OF ACTIVE ISOTOPE TO BE INCLUDED IN DENOMINATOR  -
CD              OF BURNUP EXPRESSION FOR THE SPECIFIED TEST GROUP OR   -
CD              PATH. (NOTE: THIS IS A LABEL FROM COLS. 7-12 OF THE    -
CD              ACTIVE CHAIN SPECIFIED ON CARD TYPE 09 OR IN A         -
CD              PRESTORED BURNUP CHAIN.)                               -
C                                                                      -
CN              IF THIS CARD IS PRESENT, ONLY ISOTOPES APPEARING IN    -
CN              THIS LIST CONTRIBUTE TOWARD THE CALCULATION OF THE     -
CN              BURNUP DENOMINATOR OF THE TEST GROUP OR PATH SPECIFIED -
CN              IN COLS. 7-12.                                         -
C                                                                      -
C----------------------------------------------------------------------


C----------------------------------------------------------------------
CR          ISOTOPIC CHAIN DATA (TYPE 09)                              -
C                                                                      -
CL    FORMAT-----(I2,4X,A6,I6,3(A6,E12.5))                             -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     09                                                     -
CD                                                                     -
CD  2   7-12    LABEL OF ISOTOPE UNDERGOING REACTION (REPEATED ON ALL   -
CD              CARDS THAT SPECIFY OTHER REACTIONS FOR THIS ISOTOPE)    -
CD              OR ONE OF THE PRIVILEGED LABELS PUUCH1, PUUCH2, THUCH1,-
CD              OR THUCH2 SPECIFYING ONE OF THE PRESTORED BURNUP        -
CD              CHAINS.                                                -
CD                                                                     -
CD  3   13-18   REACTION TYPE (REPEATED ON ADDITIONAL CARDS,            -
CD              IF NECESSARY).                                         -
CD              0...NO REACTION.                                       -
CD              1...(N,GAMMA) REACTION.                                -
CD              2...(N,F) REACTION.                                    -
CD              3...(N,P) REACTION.                                    -
CD              4...(N,ALPHA) REACTION.                                -
CD              5...(N,2N) REACTION.                                   -
CD              6...BETA-MINUS DECAY.                                  -
CD              7...BETA-PLUS DECAY.                                   -
CD              8...ALPHA DECAY.                                       -
CD              9...(N,D) REACTION.                                    -
CD             10...(N,T) REACTION.                                    -
CD                                                                     -
CD  4   19-24   LABEL OF PRODUCT ISOTOPE FROM THE REACTION SPECIFIED    -
CD              IN COLS. 13-18 OR THE PRIVILEGED LABEL DELETE.         -
CD                                                                     -
CD  5   25-36   YIELD FRACTION OR ISOMERIC STATE BRANCHING FRACTION     -
CD              TO THE ISOTOPE SPECIFIED IN COLS. 19-24.               -
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CD                                                                      -
CD  6   37-42   LABEL OF PRODUCT ISOTOPE FROM THE REACTION SPECIFIED    -
CD              IN COLS. 13-18.                                         -
CD                                                                      -
CD  7   43-54   YIELD FRACTION OR ISOMERIC STATE BRANCHING FRACTION     -
CD              TO THE ISOTOPE SPECIFIED IN COLS. 37-42.                -
CD                                                                      -
CD  8   55-60   LABEL OF PRODUCT ISOTOPE FROM THE REACTION SPECIFIED    -
CD              IN COLS. 13-18.                                         -
CD                                                                      -
CD  9   61-72   YIELD FRACTION OR ISOMERIC STATE BRANCHING FRACTION     -
CD              TO THE ISOTOPE SPECIFIED IN COLS. 55-60.                -
C                                                                       -
CN              ALL ISOTOPE LABELS APPEARING IN COLS. 7-12 OF ONE OR    -
CN              MORE TYPE 09 CARDS ARE DEFINED AS "ACTIVE"; THAT IS,    -
CN              THEY ARE CONSIDERED IN BURNUP/DECAY CALCULATIONS. ALL   -
CN              OTHER ISOTOPES ARE "INACTIVE"; THAT IS, THEY ARE        -
CN              ASSUMED TO UNDERGO NO TRANSMUTATIONS DURING THE         -
CN              PROBLEM. AT LEAST ONE OF THE ACTIVE ISOTOPES WHICH      -
CN              IS TO BE INCLUDED IN THE CALCULATION OF CONVERSION AND -
CN              BREEDING RATIOS MUST BE DEFINED ON A TYPE 24 CARD.      -
CN                                                                      -
CN              IF COLS. 7-12 ON ONE OF THE TYPE 09 CARDS CONTAIN ANY   -
CN              OF THE PRIVILEGED LABELS PUUCH1, PUUCH2, THUCH1,        -
CN              OR THUCH2, THE BURNUP CHAINS WILL BE DETERMINED         -
CN              FROM PRESTORED DATA.  IN THAT CASE, THE REMAINDER OF    -
CN              THE DATA ON THAT TYPE 09 CARD WILL BE IGNORED.  IF      -
CN              TYPE 09 CARDS ARE SUPPLIED WITH NORMAL ISOTOPE DATA     -
CN              IN ADDITION TO ONE OF THE PRIVILEGED LABELS, THE DATA   -
CN              WILL BE MERGED WITH THE PRESTORED CHAIN DATA.  IF        -
CN              A LABEL IN COLS. 7-12 CORRESPONDS TO ONE OF THE         -
CN              PRESTORED ISOTOPE LABELS, THE DATA ON THAT TYPE 09      -
CN              CARD WILL OVERRIDE THE PRESTORED DATA FOR THE           -
CN              CORRESPONDING REACTION TYPE.  IF IT IS DESIRED TO       -
CN              DELETE ANY OF THE PRESTORED DATA, COLS. 19-24 SHOULD    -
CN              CONTAIN THE PRIVILEGED LABEL DELETE FOR A GIVEN         -
CN              ACTIVE ISOTOPE AND REACTION TYPE SPECIFIED IN COLS.     -
CN              7-12 AND 13-18 RESPECTIVELY.  IF COLS 19-24 CONTAIN     -
CN              THE PRIVILEGED LABEL DELETE, THE REST OF THE DATA ON    -
CN              THAT CARD TYPE 09 WILL BE IGNORED.                      -
CN              THE LABELS USED IN THE PRESTORED CHAINS ARE: TH232,     -
CN              PA233, U-233, U-234, U-235, U-236, U-238, PU238,        -
CN              NP237, PU236, PU239, PU240, PU241, PU242, AM241,        -
CN              AM242, CM242, CM243, CM244, CM245, CM246, LFPP3,        -
CN              LFPP5, LFPP9, LFPPA, DUMP1, AND DUMP2.                  -
C                                                                       -
CN              IF NO TYPE 10 CARDS ARE GIVEN, THE ISOTOPE LABELS ON    -
CN              THE TYPE 09 CARDS IN COLS. 7-12 OR THE NAMES OF THE     -
CN              ISOTOPES IN THE PRESTORED BURNUP CHAINS MUST BE         -
CN              DEFINED IN THE CROSS SECTION LIBRARY ON DATA SET ISOTXS.
CN              IF ANY TYPE 10 CARDS ARE GIVEN, THE LABELS ON THE 09    -
CN              MAY BE LOCAL. THE TYPE 10 CARDS WILL RELATE THE LOCAL   -
CN              LABELS TO SPECIFIC CROSS SECTION LIBRARY LABELS.         -
CN                                                                      -
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CN              FOR REACTION TYPES 1-5 AND 9-10, IF ONLY ONE PRODUCT   -
CN              ISOTOPE IS NAMED IN COLS. 19-24, NO YIELD FRACTION NEED-
CN              BE ENTERED (1.0 IS ASSUMED). HOWEVER, IF A YIELD       -
CN              FRACTION IS SPECIFIED FOR A SINGLE PRODUCT ISOTOPE, IT -
CN              MUST BE 1.0.  IF MORE THAN ONE PRODUCT ISOTOPE IS      -
CN              LISTED, THE YIELD FRACTIONS MUST BE GIVEN FOR EACH, AND-
CN              SUM TO 1.0 EXCEPT FOR THE CASE OF FISSION, IN WHICH    -
CN              CASE THE FRACTIONS SHOULD SUM TO THE TOTAL YIELD OF    -
CN              NUCLEI/FISSION OF THE PARENT ISOTOPE (NORMALLY 2.0).   -
CN                                                                     -
CN              FOR THE RADIOACTIVE DECAY PROCESSES 6-8, NORMALLY ONLY -
CN              ONE PRODUCT ISOTOPE IS PERTINENT.  IN THESE CASES, THE -
CN              YIELD FRACTIONS NEED NOT BE 1.0, BUT THE SUM OF ALL    -
CN              OF THE YIELD FRACTIONS FOR A GIVEN ISOTOPE MUST BE     -
CN              1.0.                                                   -
CN                                                                     -
CN              IF AN ISOTOPE CONTRIBUTES TO THE TRANSMUTATION PROCESS -
CN              THEN IT IS NOT SUFFICIENT TO SPECIFY IT IN THE         -
CN              "PRODUCT ISOTOPE" FIELDS BUT IT MUST ALSO BE SPECIFIED -
CN              AT LEAST ONCE AS AN ACTIVE ISOTOPE IN FIELD 7-12 OF    -
CN              ANOTHER TYPE 09 CARD.                                  -
CN                                                                     -
CN              IF MORE THAN ONE TYPE 09 CARD IS REQUIRED TO SPECIFY   -
CN              THE PRODUCT ISOTOPES, THE LABEL OF THE ISOTOPE UNDER-  -
CN              GOING THE REACTION MUST BE REPEATED IN COLS. 7-12      -
CN              AND THE REACTION TYPE MUST BE REPEATED IN COLS. 13-18  -
CN              ON ALL SUCCEEDING TYPE 09 CARDS NEEDED TO COMPLETELY   -
CN              SPECIFY THE PRODUCT ISOTOPES.                          -
CN                                                                     -
CN              ALL ISOTOPES UNDERGOING THE (N,F) REACTION ARE         -
CN              INCLUDED IN THE CALCULATION OF BURNUP EXCEPT FOR       -
CN              THOSE BURNUP VALUES COMPUTED IN CONNECTION WITH CARD   -
CN              TYPE 06. (SEE DISCUSSION FOLLOWING CARD TYPE 06).      -
CN                                                                     -
CN              A TYPE 25 CARD MUST BE SUPPLIED FOR EACH ACTIVE ISOTOPE-
CN              WHICH HAS A REACTION TYPE OF 6, 7, OR 8.  HOWEVER,     -
CN              TYPE 25 CARDS NEED NOT BE SUPPLIED FOR ISOTOPES IN     -
CN              PRESTORED BURNUP CHAINS UNLESS IT IS DESIRED TO        -
CN              OVERRIDE THE DEFAULT DECAY CONSTANT FOR ANY OF THE     -
CN              ISOTOPES IN THE PRESTORED CHAINS OR TO DELETE SUCH     -
CN              DATA.                                                  -
CN                                                                     -
CN              NOTE THAT THE REBUS-3 CORE STORAGE REQUIREMENT GOES    -
CN              UP AS SQUARE OF NUMBER OF ACTIVE ISOTOPES.             -
CN              IN PARTICULAR, IF A PRESTORED BURNUP CHAIN IS          -
CN              SPECIFIED, THE MAXIMUM STORAGE IS REQUIRED FOR CHAIN   -
CN              THUCH2 AND PROGRESSIVELY LESSER STORAGE IS REQUIRED    -
CN              FOR CHAINS PUUCH2, THUCH1, AND PUUCH1, RESPECTIVELY.   -
C                                                                      -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          ACTIVE ISOTOPE LABEL EQUIVALENCE LIST (TYPE 10)            -
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C                                                                       -
CL    FORMAT-----(I2,4X,11A6)                                           -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     10                                                      -
CD                                                                      -
CD  2   7-12    LOCAL ISOTOPE LABEL FROM COLS. 7-12 OF TYPE 09 CARDS     -
CD              (REPEATED, IF NECESSARY, ON ADDITIONAL CARDS).          -
CD                                                                      -
CD  3   13-18   LIBRARY ISOTOPE LABEL TO BE EQUIVALENCED TO THE LOCAL   -
CD              LABEL IN COLS. 7-12.                                    -
CD                                                                      -
CD  4   19-24   LIBRARY ISOTOPE LABEL TO BE EQUIVALENCED TO THE LOCAL   -
CD              LABEL IN COLS. 7-12.                                    -
CD                                                                      -
CD  5   25-30   LIBRARY ISOTOPE LABEL TO BE EQUIVALENCED TO THE LOCAL   -
CD              LABEL IN COLS. 7-12.                                    -
CD                                                                      -
CD  6   31-36   LIBRARY ISOTOPE LABEL TO BE EQUIVALENCED TO THE LOCAL   -
CD              LABEL IN COLS. 7-12.                                    -
CD                                                                      -
CD  7   37-42   LIBRARY ISOTOPE LABEL TO BE EQUIVALENCED TO THE LOCAL   -
CD              LABEL IN COLS. 7-12.                                    -
CD                                                                      -
CD  8   43-48   LIBRARY ISOTOPE LABEL TO BE EQUIVALENCED TO THE LOCAL   -
CD              LABEL IN COLS. 7-12.                                    -
CD                                                                      -
CD  9   49-54   LIBRARY ISOTOPE LABEL TO BE EQUIVALENCED TO THE LOCAL   -
CD              LABEL IN COLS. 7-12.                                    -
CD                                                                      -
CD  10  55-60   LIBRARY ISOTOPE LABEL TO BE EQUIVALENCED TO THE LOCAL   -
CD              LABEL IN COLS. 7-12.                                    -
CD                                                                      -
CD  11  61-66   LIBRARY ISOTOPE LABEL TO BE EQUIVALENCED TO THE LOCAL   -
CD              LABEL IN COLS. 7-12.                                    -
CD                                                                      -
CD  12  67-72   LIBRARY ISOTOPE LABEL TO BE EQUIVALENCED TO THE LOCAL   -
CD              LABEL IN COLS. 7-12.                                    -
C                                                                       -
CN              CARD TYPE 10 IS REQUIRED ONLY IF THE ISOTOPE LABELS     -
CN              IN DATA SET ISOTXS DIFFER FROM THE LABELS SPECIFIED     -
CN              ON THE TYPE 09 CARDS OR VIA A PRESTORED BURNUP CHAIN,   -
CN              OR IF DIFFERENT ISOTOPE LABELS (I.E., DIFFERENT         -
CN              MICROSCOPIC CROSS SECTIONS) ARE REQUIRED FOR THE SAME   -
CN              ISOTOPE IN DIFFERENT MATERIALS. IN SUCH CASES, EACH     -
CN              MATERIAL DEFINED ON TYPE 13 OR TYPE 14 CARDS OF DATA    -
CN              SET A.NIP3 MUST CONTAIN ALL THE LIBRARY ISOTOPE LABELS  -
CN              OF THE COMPLETE CHAINS APPLICABLE TO THAT MATERIAL,     -
CN              EVEN IF THE ATOM DENSITY IS 0.0.                        -
C                                                                       -
C-----------------------------------------------------------------------
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C-----------------------------------------------------------------------
CR          REPETITIVE FUEL MANAGEMENT PATH DATA (TYPE 11)              -
C                                                                       -
CL    FORMAT-----(I2,4X,A6,I6,2(I6,2A6))                                -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     11                                                      -
CD                                                                      -
CD  2   7-12    PATH LABEL (REPEATED ON ADDITIONAL CARDS,                -
CD              IF NECESSARY).                                          -
CD                                                                      -
CD  3   13-18   NUMBER OF PREVIOUS BURN CYCLES                          -
CD              (NONEQUILIBRIUM PROBLEMS ONLY).                         -
CD                                                                      -
CD  4   19-24   STAGE NUMBER.                                           -
CD                                                                      -
CD  5   25-30   SECONDARY COMPOSITION LABEL (OR DISCHARGE LABEL).       -
CD                                                                      -
CD  6   31-36   PRIMARY COMPOSITION LABEL OR REGION LABEL OR FUEL       -
CD              MANAGEMENT GROUP LABEL.                                 -
CD                                                                      -
CD  7   37-42   STAGE NUMBER.                                           -
CD                                                                      -
CD  8   43-48   SECONDARY COMPOSITION LABEL (OR DISCHARGE LABEL).       -
CD                                                                      -
CD  9   49-54   PRIMARY COMPOSITION LABEL OR REGION LABEL OR FUEL       -
CD              MANAGEMENT GROUP LABEL.                                 -
C                                                                       -
CN              IF TYPE 35 CARDS ARE PROVIDED, ANY TYPE 11 CARDS WILL   -
CN              BE IGNORED.                                             -
CN                                                                      -
CN              EACH FUEL MANAGEMENT PATH IS DEFINED BY ITS STAGE       -
CN              NUMBERS IN ASCENDING NUMERICAL ORDER (1,2,3,...,        -
CN              NOT NECESSARILY ORDERED ON THE CARDS). THE FUEL TO BE   -
CN              MOVED IS IDENTIFIED BY THE SECONDARY COMPOSITION LABEL,-
CN              WHILE THE LOCATION OF THE FUEL IN THE REACTOR IS GIVEN -
CN              BY THE PRIMARY COMPOSITION LABEL (WHICH IS ASSIGNED     -
CN              TO REGIONS VIA A.NIP3 TYPE 15 CARDS) OR BY A REGION     -
CN              (OR FUEL MANAGEMENT GROUP) LABEL.  SEE CARD TYPE 45     -
CN              FOR A DESCRIPTION OF THE LATTER.  FOR A GIVEN PATH,     -
CN              COLS. 31-36 AND 49-54 MUST EITHER BE ALL PRIMARY        -
CN              COMPOSITION LABELS, OR ALL REGIONS, OR ALL FUEL         -
CN              MANAGEMENT GROUP LABELS.                                -
CN                                                                      -
CN              THE SAME SECONDARY COMPOSITION MUST BE USED IN ALL      -
CN              STAGES OF A GIVEN PATH.                                 -
CN                                                                      -
CN              IF PRIMARY COMPOSITION LABELS OR FUEL MANAGEMENT GROUP -
CN              LABELS ARE BEING USED TO DEFINE A PARTICULAR PATH, ALL -
CN              OF THESE LABELS MUST BE THE SAME OR BLANK.  THIS IS     -
CN              NECESSARY SINCE IT IS NOT POSSIBLE TO KNOW WHICH OF THE-
CN              REGIONS ASSOCIATED WITH ONE OF THE STAGES IS CONNECTED -
CN              WITH A PARTICULAR REGION IN THE NEXT STAGE IF THE FUEL -
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```
CN              IS BEING SHUFFLED.                                      -
CN                                                                      -
CN              IF THE PATH HAS K STAGES, THE DISCHARGE LABEL (SEE      -
CN              CARD TYPES 14 AND 15) FOR THIS PATH IS ENTERED AS THE   -
CN              SECONDARY COMPOSITION LABEL FOR THE K+1 STAGE NUMBER.   -
CN              FOR THIS CASE, THE PRIMARY COMPOSITION LABEL OR REGION  -
CN              (OR FUEL MANAGEMENT GROUP) LABEL SHOULD BE BLANK.  THE  -
CN              DISCHARGE LABEL MAY BE OMITTED IF NO FUEL IS RECYCLED   -
CN              (NO REPROCESSING PLANTS SPECIFIED).                     -
CN                                                                      -
CN              FOR EQUILIBRIUM PROBLEMS, IF A SECONDARY COMPOSITION    -
CN              RESIDES IN ONE REGION FOR SEVERAL STAGES OF A MULTI-    -
CN              STAGE PATH AND IN SOME OTHER REGION FOR OTHER STAGES,   -
CN              THE USER MUST BE CAREFUL THAT THE VOLUMES OF THE TWO    -
CN              REGIONS ARE COMPATIBLE WITH THE FRACTIONS OF THE        -
CN              COMPOSITIONS WHICH ARE BEING TRANSFERRED.  FOR EXAMPLE, -
CN              IF A SECONDARY COMPOSITION RBS1 IS LOADED INTO REGION   -
CN              BZ11 IN STAGE 1, REMAINS THERE FOR STAGE 2, AND THEN    -
CN              IS MOVED TO REGION BZ31 FOR STAGE 3 AND REMAINS IN      -
CN              REGION BZ31 FOR STAGES 4 AND 5, THE VOLUMES OF REGIONS  -
CN              BZ11 AND BZ31 SHOULD BE IN THE RATIO OF 2.0/3.0.        -
CN              THIS CAN BE SEEN SINCE FOR STAGE 3, HALF OF THE VOLUME  -
CN              OF REGION BZ11 IS BEING COMBINED WITH TWO-THIRDS OF THE-
CN              VOLUME OF REGION BZ31 AND MUST BE CONTAINED IN REGION   -
CN              BZ31.  DENOTING THE VOLUMES OF REGIONS BZ11 AND BZ31    -
CN              AS V1 AND V2 RESPECTIVELY, ALGEBRAICALLY ONE MUST       -
CN              SATISFY THE MATERIAL CONSERVATION EQUATION              -
CN                    0.5(V1)+0.33333(V2)+0.33333(V2)=V2.               -
CN                                                                      -
CN              THE USE OF THE TYPE 11 CARDS MAY BE ILLUSTRATED BY THE  -
CN              FOLLOWING EXAMPLE.  CONSIDER A FOUR REGION CORE INTO    -
CN              WHICH 4 FUEL TYPES ARE LOADED AND SHUFFLED THROUGH 3    -
CN              BURN STEPS.  THE CONFIGURATION CAN BE PICTURED AS       -
CN                                                                      -
CN              BURN             MATERIAL CONTAINED IN                  -
CN              CYCLE     CORE1     CORE2     CORE3     CORE4           -
CN              -----   --------  --------  --------  --------          -
CN                1     FUEL1(0)  FUEL2(0)  FUEL3(2)  FUEL4(0)          -
CN                2     FUEL3(0)  FUEL1(1)  FUEL2(1)  FUEL4(1)          -
CN                3     FUEL4(2)  FUEL3(1)  FUEL1(2)  FUEL2(2)          -
CN                                                                      -
CN              THE NUMBERS IN PARENTHESES ARE THE NUMBER OF PREVIOUS   -
CN              BURN STEPS THE PARTICULAR FUEL HAS UNDERGONE AT THAT    -
CN              STAGE AND LOCATION IN THE SYSTEM.  THIS SEQUENCE        -
CN              WOULD BE ACCOMPLISHED BY SUPPLYING THE FOLLOWING TYPE   -
CN              11 CARDS WHICH ARE ILLUSTRATED BELOW IN FREE FORMAT     -
CN              STYLE INPUT.                                            -
CN                                                                      -
CN                 11 PATH1 0 1 FUEL1 CORE1 2 FUEL1 CORE2               -
CN                 11 PATH1 0 3 FUEL1 CORE3                             -
CN                 11 PATH2 0 1 FUEL2 CORE2 2 FUEL2 CORE3               -
CN                 11 PATH2 0 3 FUEL2 CORE4                             -
CN                 11 PATH3 2 1 FUEL3 CORE3 2 FUEL3 CORE1               -
CN                 11 PATH3 2 3 FUEL3 CORE2                             -
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CN                 11 PATH4 0 1 FUEL4 CORE4 2 FUEL4 CORE4              -
CN                 11 PATH4 0 3 FUEL4 CORE1                            -
CN                                                                     -
CN              NOTE THAT OPERATIONALLY, THE CONFIGURATION ILLUSTRATED -
CN              ABOVE AS BURN CYCLE 1 WOULD BE REACHED ONLY AFTER      -
CN              PERFORMING 3 BURN CYCLES USING THE TYPE 11 CARDS LISTED-
CN              ABOVE.  THUS, COLS. 67-72 ON CARD TYPE 03 SHOULD       -
CN              CONTAIN AT LEAST 5 TO BEGIN APPROXIMATING THE REPEATING-
CN              FUEL MANAGEMENT SCHEME INDICATED ABOVE.  THE REACTOR   -
CN              FOR EACH OF THESE CYCLES WOULD BE AS INDICATED BELOW.  -
CN                                                                     -
CN              BURN              MATERIAL CONTAINED IN                -
CN              CYCLE     CORE1     CORE2     CORE3     CORE4          -
CN              -----   --------  --------  --------  --------         -
CN                1     FUEL1(0)  FUEL2(0)  FUEL3(0)  FUEL4(0)         -
CN                2     FUEL3(0)  FUEL1(1)  FUEL2(1)  FUEL4(1)         -
CN                3     FUEL4(2)  FUEL3(1)  FUEL1(2)  FUEL2(2)         -
CN                4     FUEL1(0)  FUEL2(0)  FUEL3(2)  FUEL4(0)         -
CN                5     FUEL3(0)  FUEL1(1)  FUEL2(1)  FUEL4(1)         -
CN                6     FUEL4(2)  FUEL3(1)  FUEL1(2)  FUEL2(2)         -
CN                7      ...                                           -
CN                                                                     -
CN              A SECONDARY COMPOSITION MUST BE DEFINED ON DATA SET    -
CN              A.NIP3 TYPE 14 CARDS, AND BE COMPRISED OF MATERIALS    -
CN              DEFINED ON DATA SET A.NIP3 TYPE 13 OR TYPE 14 CARDS. A -
CN              PRIMARY COMPOSITION MUST BE DEFINED ON DATA SET A.NIP3 -
CN              TYPE 14 CARDS IN TERMS OF A SINGLE SECONDARY           -
CN              COMPOSITION, AND BE ASSIGNED TO A REGION VIA DATA SET  -
CN              A.NIP3 TYPE 15 CARDS.                                  -
CN                                                                     -
CN              IN STAGE 1 OF EACH PATH OF AN EQUILIBRIUM PROBLEM, AND -
CN              IN STAGE 1 OF EACH PATH HAVING COLS. 13-18 EQUAL TO 0  -
CN              OF A NON-EQUILIBRIUM PROBLEM, THE SECONDARY COMPOSITION-
CN              TO PRIMARY COMPOSITION/REGION CORRESPONDENCE MUST AGREE-
CN              WITH THAT IMPLIED FROM THE DATA SET A.NIP3 TYPE 14/15  -
CN              CARDS.                                                 -
CN                                                                     -
CN              NOTE THAT FOR AN EQUILIBRIUM PROBLEM, IF A REGION OR   -
CN              COMPOSITION APPEARS IN N STAGES OF A PATH, THEN AT THE -
CN              BOEC, THAT REGION WILL CONTAIN FRESH FUEL, ONCE BURNED -
CN              FUEL, TWICE BURNED FUEL,..., UP TO N-I TH BURNED FUEL  -
CN              IN THE EQUILIBRIUM CONFIGURATION.                      -
CN                                                                     -
CN              IN DEFINING THE MATERIALS USED TO MAKE UP SECONDARY    -
CN              COMPOSITIONS ON TYPE 13 OR TYPE 14 CARDS OF DATA SET   -
CN              A.NIP3, IF CARD TYPE 04 OF DATA SET A.BURN AND THE     -
CN              ASSOCIATED EXTERNAL CYCLE CARDS ARE PRESENT, THE ATOM  -
CN              DENSITY OF ALL POSSIBLE ACTIVE ISOTOPES IN EACH        -
CN              MATERIAL MUST BE SET TO 1.0. THE ATOM DENSITIES OF     -
CN              INACTIVE ISOTOPES ARE THE ACTUAL VALUES (IN UNITS OF   -
CN              ATOMS/CC * 1.0E-24).                                   -
CN                                                                     -
CN              NOTE THAT FOR NON-EQUILIBRIUM PROBLEMS, IF COLS. 67-72 -
CN              ON CARD TYPE 03 IS 0, ONLY STAGE NUMBER 1 ON THE TYPE  -
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CN              11 CARDS IS PERTINENT.  OTHER STAGES ON THE TYPE 11    -
CN              CARDS CAN BE REACHED FOR NON-EQUILIBRIUM PROBLEMS ONLY -
CN              IF MORE THAN ONE FUEL MANAGEMENT OPERATION IS CARRIED  -
CN              OUT.                                                   -
C                                                                      -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          REACTOR CHARGE SPECIFICATIONS (TYPE 12)                    -
C                                                                      -
CL    FORMAT-----(I2,4X,A6,6X,A6,4E12.5)                               -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ==========================================================-
CD  1   1-2     12                                                     -
CD                                                                     -
CD  2   7-12    PATH LABEL (SEE CARD TYPE 11 OR CARD TYPE 35).          -
CD                                                                     -
CD  3   19-24   FUEL FABRICATION LABEL (SEE CARD TYPE 13).             -
CD                                                                     -
CD  4   25-36   REFABRICATION TIME (IN DAYS).                          -
CD                                                                     -
CD  5   37-48   PRELOADING STORAGE TIME (IN DAYS).                     -
CD                                                                     -
CD  6   49-60   INITIAL ENRICHMENT, E(M)(0) (SEE CARD TYPE 04).       -
CD                                                                     -
CD  7   61-72   ENRICHMENT MODIFICATION FACTOR, DELTA(M)              -
CD              (SEE CARD TYPE 04). (DEFAULT=1.0).                     -
C                                                                      -
CN              ENRICHMENT IS DEFINED AS THE VOLUME RATIO,             -
CN                                                                     -
CN                    CLASS 1/(CLASS 1 + CLASS 2)                      -
C                                                                      -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          FUEL FABRICATION DATA (TYPE 13)                            -
C                                                                      -
CL    FORMAT-----(I2,4X,A6,6X,3(A6,E12.5))                             -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ==========================================================-
CD  1   1-2     13                                                     -
CD                                                                     -
CD  2   7-12    FUEL FABRICATION LABEL.                                -
CD                                                                     -
CD  3   19-24   ACTIVE ISOTOPE LABEL.                                  -
CD                                                                     -
CD  4   25-36   FABRICATION DENSITY OF PURE ISOTOPE                    -
CD              (ATOMS/CC * 1.0E-24).                                  -
CD                                                                     -
CD  5   37-42   ACTIVE ISOTOPE LABEL.                                  -
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CD                                                                      -
CD  6    43-54   FABRICATION DENSITY OF PURE ISOTOPE                    -
CD               (ATOMS/CC * 1.0E-24).                                  -
CD                                                                      -
CD  7    55-60   ACTIVE ISOTOPE LABEL.                                  -
CD                                                                      -
CD  8    61-72   FABRICATION DENSITY OF PURE ISOTOPE                    -
CD               (ATOMS/CC * 1.0E-24).                                  -
C                                                                       -
CN               EACH FUEL FABRICATION LABEL IDENTIFIES A SET OF        -
CN               ISOTOPIC FABRICATION DENSITIES WHICH YIELD THE DESIRED -
CN               DENSITY OF HEAVY METAL (IN GM/CC) IN THE FABRICATED    -
CN               FUEL. THE SPECIFIC VALUE OF THE HEAVY METAL DENSITY    -
CN               WILL DEPEND ON THE PARTICULAR CHEMICAL AND PHYSICAL    -
CN               COMPOSITION OF THE FUEL CHARGES BEING FABRICATED, E.G.,-
CN               OXIDE OR CARBIDE FUEL AT SOME PERCENTAGE OF THEO-      -
CN               RETICAL DENSITY (TD) AND WEIGHT PER CENT HEAVY METAL.  -
CN                                                                      -
CN               FABRICATION DENSITY OF PURE ISOTOPE MEANS THE NUMBER   -
CN               OF ATOMS PER UNIT VOLUME WHICH WOULD BE REQUIRED IN A  -
CN               FABRICATED CHARGE TO GIVE THE DESIRED HEAVY METAL      -
CN               DENSITY ASSUMING ITS COMPOSITION IS 100 PER CENT THIS  -
CN               SINGLE ACTIVE ISOTOPE, I.E., NO ISOTOPIC DISTRIBUTION  -
CN               IN THE ELEMENT.                                        -
CN                                                                      -
CN               AS AN EXAMPLE, SUPPOSE THE FABRICATED FUEL IS TO BE    -
CN               PUO2 AT 95 PER CENT TD. ASSUMING A TD OF 11.4 GM/CC    -
CN               AND 88 WEIGHT PER CENT HEAVY METAL, THIS GIVES A       -
CN               DESIRED HEAVY METAL FABRICATION DENSITY OF 9.5304      -
CN               GM/CC. USING THE VALUE OF 0.6022054E24 FOR AVOGADRO'S  -
CN               NUMBER (SEE CARD TYPE 28) AND THE FOLLOWING ATOMIC     -
CN               WEIGHTS, THE REQUIRED ISOTOPIC FABRICATION DENSITIES   -
CN               ARE,                                                   -
CN                  ISOTOPE     ATOMIC     FABRICATION DENSITY         -
CN                              WEIGHT       OF PURE ISOTOPE           -
CN                   PU238     238.0495        2.41095E-2               -
CN                   PU239     239.0522        2.40084E-2               -
CN                   PU240     240.0540        2.39082E-2               -
CN                   PU241     241.0563        2.38088E-2               -
CN                   PU242     242.0587        2.37102E-2               -
CN                                                                      -
CN               THE CORRESPONDING ATOM DENSITIES OF THE INACTIVE       -
CN               ISOTOPES IN THE FABRICATED FUEL ARE ENTERED DIRECTLY   -
CN               ON THE APPROPRIATE A.NIP3 TYPE 13 OR TYPE 14 CARDS.  IN-
CN               THIS EXAMPLE THE INACTIVE ISOTOPE IS OXYGEN AT AN ATOM -
CN               DENSITY OF 4.89376E-2. ALL ACTIVE ISOTOPE LABELS MUST  -
CN               BE DEFINED ON TYPE 09 CARDS OR VIA THE PRESTORED       -
CN               BURNUP CHAINS.                                         -
CN                                                                      -
CN               SEE ALSO THE COMMENTS FOR THE TYPES 17 AND 22 CARDS    -
CN               REGARDING THE NEED TO SPECIFY ALL OF THE ACTIVE        -
CN               ISOTOPES ON THE TYPE 13 CARDS WHICH ARE SUPPLIED FROM  -
CN               EXTERNAL FEEDS OR REPROCESSING PLANTS AND WHICH WILL   -
CN               BE USED TO FABRICATE FUEL FOR ANY OF THE PATHS.        -
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C                                                                              -
C-------------------------------------------------------------------------------


C-------------------------------------------------------------------------------
CR          REACTOR DISCHARGE COOLING TIMES (TYPE 14)                          -
C                                                                              -
CL    FORMAT-----(I2,4X,3(A6,E12.5))                                           -
C                                                                              -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                        -
CD  =  =======  ========================================================      -
CD  1   1-2     14                                                             -
CD                                                                             -
CD  2   7-12    REACTOR DISCHARGE LABEL.                                       -
CD                                                                             -
CD  3   13-24   COOLING TIME (IN DAYS).                                        -
CD                                                                             -
CD  4   25-30   REACTOR DISCHARGE LABEL.                                       -
CD                                                                             -
CD  5   31-42   COOLING TIME (IN DAYS).                                        -
CD                                                                             -
CD  6   43-48   REACTOR DISCHARGE LABEL.                                       -
CD                                                                             -
CD  7   49-60   COOLING TIME (IN DAYS).                                        -
C                                                                              -
CN              THE TYPE 14 CARDS SHOULD NOT BE SUPPLIED IF THE DATA           -
CN              MANAGEMENT IS SPECIFIED USING THE TYPE 35 CARDS.               -
CN                                                                             -
CN              COOLING TIME MAY INCLUDE THE TIME REQUIRED FOR                 -
CN              DELIVERY FROM COOLER TO REPROCESSING PLANT                     -
CN              (SEE CARD TYPE 15).                                            -
C                                                                              -
C-------------------------------------------------------------------------------


C-------------------------------------------------------------------------------
CR          REACTOR DISCHARGE DESTINATION DATA (TYPE 15)                       -
C                                                                              -
CL    FORMAT-----(I2,4X,A6,6X,3(A6,E12.5))                                     -
C                                                                              -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                        -
CD  =  =======  ========================================================      -
CD  1   1-2     15                                                             -
CD                                                                             -
CD  2   7-12    REACTOR DISCHARGE LABEL (REPEATED ON ADDITIONAL CARDS,          -
CD              IF NECESSARY).                                                 -
CD                                                                             -
CD  3   19-24   REPROCESSING PLANT LABEL.                                      -
CD                                                                             -
CD  4   25-36   FRACTION OF DISCHARGE TO BE DELIVERED TO REPROCESSING          -
CD              PLANT.                                                         -
CD                                                                             -
CD  5   37-42   REPROCESSING PLANT LABEL.                                      -
CD                                                                             -
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CD  6   43-54   FRACTION OF DISCHARGE TO BE DELIVERED TO REPROCESSING  -
CD              PLANT.                                                -
CD                                                                    -
CD  7   55-60   REPROCESSING PLANT LABEL.                             -
CD                                                                    -
CD  8   61-72   FRACTION OF DISCHARGE TO BE DELIVERED TO REPROCESSING  -
CD              PLANT.                                                -
C                                                                     -
CN              THE TYPE 15 CARDS SHOULD NOT BE SUPPLIED IF THE DATA  -
CN              MANAGEMENT IS SPECIFIED USING THE TYPE 35 CARDS.      -
CN                                                                    -
CN              ALL REACTOR DISCHARGE NOT DELIVERED TO SOME           -
CN              REPROCESSING PLANT WILL BE CONSIDERED SOLD.           -
C                                                                     -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          REPROCESSING PLANT SPECIFICATIONS (TYPE 16)               -
C                                                                     -
CL    FORMAT-----(I2,4X,3A6,2E12.5)                                   -
C                                                                     -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY               -
CD  =  =======  ========================================================-
CD  1   1-2     16                                                    -
CD                                                                    -
CD  2   7-12    REPROCESSING PLANT LABEL.                             -
CD                                                                    -
CD  3   13-18   RECOVERY FACTOR SPECIFICATION LABEL.                  -
CD                                                                    -
CD  4   19-24   CLASS SEPARATION SPECIFICATION LABEL.                 -
CD                                                                    -
CD  5   25-36   REPROCESSING TIME (IN DAYS).                          -
CD                                                                    -
CD  6   37-48   VOLUME OF REPROCESSING PLANT INITIAL BATCH            -
CD              OUTPUT (CM**3).                                       -
C                                                                     -
CN              THE TYPE 16 CARDS SHOULD NOT BE SUPPLIED IF THE DATA  -
CN              MANAGEMENT IS SPECIFIED USING THE TYPE 35 CARDS.      -
CN                                                                    -
CN              THE CLASS SEPARATION SPECIFICATION LABEL IN COLS. 19-24-
CN              MUST ALSO APPEAR IN COLS. 7-12 ON A TYPE 18 CARD.     -
CN                                                                    -
CN              COLS. 37-48 ARE PERTINENT ONLY IF CARD TYPE 23 IS     -
CN              PROVIDED.                                             -
C                                                                     -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          RECOVERY FACTOR DATA (TYPE 17)                            -
C                                                                     -
CL    FORMAT-----(I2,4X,A6,6X,3(A6,E12.5))                            -
C                                                                     -
```

```
CD  #  COLUMNS          CONTENTS...IMPLICATION, IF ANY                  -
CD  =  =======  ========================================================-
CD  1   1-2     17                                                      -
CD                                                                      -
CD  2   7-12    RECOVERY FACTOR SPECIFICATION LABEL (REPEATED ON         -
CD              ADDITIONAL CARDS, IF NECESSARY).                        -
CD                                                                      -
CD  3   19-24   ACTIVE ISOTOPE LABEL.                                   -
CD                                                                      -
CD  4   25-36   RECOVERY FACTOR.                                        -
CD                                                                      -
CD  5   37-42   ACTIVE ISOTOPE LABEL.                                   -
CD                                                                      -
CD  6   43-54   RECOVERY FACTOR.                                        -
CD                                                                      -
CD  7   55-60   ACTIVE ISOTOPE LABEL.                                   -
CD                                                                      -
CD  8   61-72   RECOVERY FACTOR.                                        -
C                                                                       -
CN              THE TYPE 17 CARDS SHOULD NOT BE SUPPLIED IF THE DATA    -
CN              MANAGEMENT IS SPECIFIED USING THE TYPE 35 CARDS.        -
CN                                                                      -
CN              ALL ACTIVE ISOTOPES SPECIFIED FOR A PARTICULAR RECOVERY-
CN              FACTOR SPECIFICATION LABEL MUST ALSO APPEAR ON A TYPE   -
CN              13 CARD IF THE CORRESPONDING REPROCESSING PLANT         -
CN              WILL BE USED TO FABRICATE FUEL FOR SOME PATH.  THE      -
CN              PATHS ASSOCIATED WITH VARIOUS REPROCESSING PLANTS ARE   -
CN              SPECIFIED ON THE TYPE 19 AND 20 CARDS, THE REPROCESSING-
CN              PLANTS ASSOCIATED WITH THE VARIOUS RECOVERY FACTOR      -
CN              LABELS ON THE TYPE 16 CARDS, AND THE FABRICATION LABELS-
CN              ASSOCIATED WITH THE VARIOUS PATH LABELS ON THE TYPE 12  -
CN              CARDS.                                                  -
CN                                                                      -
CN              ALL ACTIVE ISOTOPE LABELS MUST BE DEFINED ON TYPE 09    -
CN              CARDS OR VIA THE PRESTORED BURNUP CHAINS.               -
CN                                                                      -
CN              RECOVERY FACTOR APPLIES TO AMOUNTS LEFT AFTER DECAY     -
CN              DURING REPROCESSING TIME.                               -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          CLASS SEPARATION DATA (TYPE 18)                             -
C                                                                       -
CL    FORMAT-----(I2,4X,A6,6X,3(A6,E12.5))                              -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     18                                                      -
CD                                                                      -
CD  2   7-12    CLASS SEPARATION SPECIFICATION LABEL (REPEATED ON        -
CD              ADDITIONAL CARDS, IF NECESSARY).                        -
CD                                                                      -
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CD  3   19-24   ACTIVE ISOTOPE LABEL.                                    -
CD                                                                      -
CD  4   25-36   FRACTION OF ISOTOPE ASSIGNED TO CLASS 1 FUEL.           -
CD                                                                      -
CD  5   37-42   ACTIVE ISOTOPE LABEL.                                    -
CD                                                                      -
CD  6   43-54   FRACTION OF ISOTOPE ASSIGNED TO CLASS 1 FUEL.           -
CD                                                                      -
CD  7   55-60   ACTIVE ISOTOPE LABEL.                                    -
CD                                                                      -
CD  8   61-72   FRACTION OF ISOTOPE ASSIGNED TO CLASS 1 FUEL.           -
C                                                                       -
CN              ALL ACTIVE ISOTOPE LABELS MUST BE DEFINED ON TYPE 09    -
CN              CARDS.                                                  -
CN                                                                      -
CN              CARD TYPE 18 DEFINES WHICH ISOTOPES ARE TO BE ASSIGNED  -
CN              TO CLASS 1 FUEL.                                        -
CN                                                                      -
CN              CLASS 1 FUEL IS NORMALLY CONSIDERED TO BE FUEL THAT     -
CN              ADDS GREATER REACTIVITY TO THE REACTOR THAN DOES CLASS  -
CN              2 FUEL. THE COMPLEMENTS OF THE FRACTIONS GIVEN IN COLS.-
CN              25-36, 43-54, AND 61-72 ARE THE FRACTIONS ASSIGNED TO   -
CN              CLASS 2 FUEL.                                           -
CN                                                                      -
CN              ANY ACTIVE ISOTOPE SPECIFIED ON A TYPE 09 CARD OR IN    -
CN              A PRESTORED BURNUP CHAIN THAT IS NOT GIVEN ON CARD      -
CN              TYPE 18 WILL HAVE A FRACTION 0.0 ASSIGNED TO CLASS 1    -
CN              FUEL.                                                   -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          CLASS 1 FABRICATION SPECIFICATIONS (TYPE 19)                -
C                                                                       -
CL    FORMAT-----(I2,4X,A6,6X,2(A6,I6,E12.5))                           -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     19                                                      -
CD                                                                      -
CD  2   7-12    PATH LABEL OF FABRICATION PROCESS OR SALE LABEL          -
CD              (REPEATED ON ADDITIONAL CARDS, IF NECESSARY).           -
CD                                                                      -
CD  3   19-24   REPROCESSING PLANT LABEL OR EXTERNAL FEED LABEL OF      -
CD              FUEL USED IN FABRICATION.                               -
CD                                                                      -
CD  4   25-30   PRIORITY LEVEL TO BE ASSIGNED TO ABOVE SOURCE.          -
CD                                                                      -
CD  5   31-42   DISTRIBUTION FRACTION (DEFAULT=1.0).                    -
CD                                                                      -
CD  6   43-48   REPROCESSING PLANT LABEL OR EXTERNAL FEED LABEL OF      -
CD              FUEL USED IN FABRICATION.                               -
CD                                                                      -
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CD  7   49-54   PRIORITY LEVEL TO BE ASSIGNED TO ABOVE SOURCE.          -
CD                                                                      -
CD  8   55-66   DISTRIBUTION FRACTION (DEFAULT=1.0).                    -
C                                                                       -
CN              CARD TYPES 19 AND 20 SPECIFY THE METHOD OF SELECTING    -
CN              FUEL FOR CLASS 1 AND CLASS 2 FABRICATION.               -
CN                                                                      -
CN              THE PRIORITY LEVEL ESTABLISHES THE ORDER OF PREFERENCE -
CN              FOR USE OF REPROCESSING PLANT OUTPUT OR EXTERNAL FEED   -
CN              FUEL IN FABRICATION OF THE VARIOUS BATCHES OF THE       -
CN              REACTOR CHARGE. THE MOST STRAIGHTFORWARD SYSTEM IS ONE -
CN              IN WHICH ONLY ONE BATCH (SPECIFIED BY A PATH OR SALE    -
CN              LABEL) REQUIRES ATOMS FROM A GIVEN PLANT OR EXTERNAL    -
CN              FEED AT EACH PRIORITY LEVEL. IN THIS CASE ALL ATOMS     -
CN              REQUIRED FOR THE BATCH WITH PRIORITY 1 WILL BE TAKEN    -
CN              FIRST, THEN THOSE REQUIRED FOR PRIORITY 2 (IF ANY       -
CN              REMAIN), AND SO ON. PRIORITY LEVELS USED MUST BE        -
CN              CONSECUTIVE STARTING FROM 1 WITH NO OMISSIONS.          -
CN                                                                      -
CN              IF TWO OR MORE PATH OR SALE LABELS SPECIFY THE SAME     -
CN              PLANT OUTPUT OR FEED AT THE SAME PROIRITY LEVEL, THE    -
CN              AVAILABLE ATOMS WILL FIRST BE DISTRIBUTED IN PROPORTION-
CN              TO THE DISTRIBUTION FRACTION OF EACH CHARGE. IF THE     -
CN              REQUIREMENTS OF SOME OF THESE BATCHES ARE SATISFIED     -
CN              WHILE OTHERS ARE NOT, FURTHER PROPORTIONAL              -
CN              DISTRIBUTIONS ARE MADE TO THE REMAINING BATCHES UNTIL   -
CN              EITHER ALL REQUIREMENTS ARE SATISFIED OR ALL AVAILABLE -
CN              ATOMS ARE USED.                                         -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          CLASS 2 FABRICATION SPECIFICATIONS (TYPE 20)                -
C                                                                       -
CL    FORMAT-----(I2,4X,A6,6X,2(A6,I6,E12.5))                           -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     20                                                      -
CD                                                                      -
CD  2   7-12    PATH LABEL OF FABRICATION PROCESS OR SALE LABEL          -
CD              (REPEATED ON ADDITIONAL CARDS, IF NECESSARY).           -
CD                                                                      -
CD  3   19-24   REPROCESSING PLANT LABEL OR EXTERNAL FEED LABEL OF      -
CD              FUEL USED IN FABRICATION.                               -
CD                                                                      -
CD  4   25-30   PRIORITY LEVEL TO BE ASSIGNED TO ABOVE SOURCE.          -
CD                                                                      -
CD  5   31-42   DISTRIBUTION FRACTION (DEFAULT=1.0).                    -
CD                                                                      -
CD  6   43-48   REPROCESSING PLANT LABEL OR EXTERNAL FEED LABEL OF      -
CD              FUEL USED IN FABRICATION.                               -
CD                                                                      -
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CD  7   49-54   PRIORITY LEVEL TO BE ASSIGNED TO ABOVE SOURCE.          -
CD                                                                      -
CD  8   55-66   DISTRIBUTION FRACTION (DEFAULT=1.0).                    -
C                                                                       -
CN              THE PRIORITY SYSTEM IS IDENTICAL TO THAT DESCRIBED      -
CN              FOR CLASS 1 MAKEUP ON CARD TYPE 19.                     -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          EXTERNAL FEED SPECIFICATIONS (TYPE 21)                      -
C                                                                       -
CL    FORMAT-----(I2,4X,2A6,E12.5)                                      -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     21                                                      -
CD                                                                      -
CD  2   7-12    EXTERNAL FEED LABEL.                                    -
CD                                                                      -
CD  3   13-18   CLASS SEPARATION SPECIFICATION LABEL.                   -
CD                                                                      -
CD  4   19-30   VOLUME OF FEED (CM**3). (DEFAULT=1.0E+30).              -
C                                                                       -
CN              THE VOLUME OF ONE OF THE EXTERNAL FEEDS MUST BE LARGE   -
CN              ENOUGH TO ENSURE THAT THERE WILL ALWAYS BE ENOUGH       -
CN              FUEL TO FABRICATE ALL CHARGES. AN INFINITE VOLUME       -
CN              (I.E. 1.0E+30 CM**3) WILL BE ASSIGNED TO THE FEED       -
CN              IF COLS. 19-30 ARE BLANK.                               -
CN                                                                      -
CN              THE CLASS SEPARATION SPECIFICATION LABEL IN COLS. 13-18-
CN              MUST ALSO APPEAR IN COLS. 7-12 ON A TYPE 18 CARD.       -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          EXTERNAL FEED COMPOSITION (TYPE 22)                         -
C                                                                       -
CL    FORMAT-----(I2,4X,A6,6X,3(A6,E12.5))                              -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     22                                                      -
CD                                                                      -
CD  2   7-12    EXTERNAL FEED LABEL (REPEATED ON ADDITIONAL CARD,        -
CD              IF NECESSARY).                                          -
CD                                                                      -
CD  3   19-24   ACTIVE ISOTOPE LABEL.                                   -
CD                                                                      -
CD  4   25-36   ATOMIC DENSITY (ATOMS/CC * 1.0E-24).                    -
CD                                                                      -
CD  5   37-42   ACTIVE ISOTOPE LABEL.                                   -
```

```
CD                                                                      -
CD  6   43-54   ATOMIC DENSITY (ATOMS/CC * 1.0E-24).                    -
CD                                                                      -
CD  7   55-60   ACTIVE ISOTOPE LABEL.                                   -
CD                                                                      -
CD  8   61-72   ATOMIC DENSITY (ATOMS/CC * 1.0E-24).                    -
C                                                                       -
CN                                                                      -
CN                      * * *  OR  * * *                                -
CN                                                                      -
C                                                                       -
CD  1   1-2     22                                                      -
CD                                                                      -
CD  2   7-12    EXTERNAL FEED LABEL (REPEATED ON ADDITIONAL CARD,        -
CD              IF NECESSARY).                                          -
CD                                                                      -
CD  3   19-24   ACTIVE ISOTOPE LABEL.                                   -
CD                                                                      -
CD  4   25-36   RELATIVE ISOTOPIC CONCENTRATION.                        -
CD                                                                      -
CD  5   37-42   ACTIVE ISOTOPE LABEL.                                   -
CD                                                                      -
CD  6   43-54   RELATIVE ISOTOPIC CONCENTRATION.                        -
CD                                                                      -
CD  7   55-60   ACTIVE ISOTOPE LABEL.                                   -
CD                                                                      -
CD  8   61-72   RELATIVE ISOTOPIC CONCENTRATION.                        -
C                                                                       -
CN              ALL ACTIVE ISOTOPE LABELS MUST BE DEFINED ON            -
CN              TYPE 09 CARDS OR VIA A PRESTORED BURNUP CHAIN.          -
CN                                                                      -
CN              THE NUMBER OF ATOMS OF EACH ACTIVE ISOTOPE SUPPLIED     -
CN              BY EACH EXTERNAL FEED IS OBTAINED FROM THE PRODUCT OF   -
CN              THE TYPE 22 DATA AND THE CORRESPONDING VOLUME FOR THAT  -
CN              FEED SPECIFIED ON THE TYPE 21 CARDS.  IF THE VOLUME OF  -
CN              THE EXTERNAL FEED IS IMMATERIAL TO THE PROBLEM          -
CN              SOLUTION, I.E., NOT A CONSTRAINT, ANY RELATIVE ISOTOPIC-
CN              FRACTIONS PROPORTIONAL TO THE ACTUAL ATOMIC              -
CN              CONCENTRATIONS MAY BE USED.                             -
CN                                                                      -
CN              ALL ACTIVE ISOTOPES SPECIFIED FOR A PARTICULAR EXTERNAL-
CN              FEED LABEL MUST ALSO APPEAR ON A TYPE 13 CARD IF THAT   -
CN              EXTERNAL FEED WILL BE USED TO FABRICATE THE FUEL FOR    -
CN              SOME PATH.  THE PATHS ASSOCIATED WITH VARIOUS EXTERNAL  -
CN              FEEDS ARE SPECIFIED ON THE TYPE 19 AND 20 CARDS, AND    -
CN              THE FABRICATION LABELS ASSOCIATED WITH THE VARIOUS PATH-
CN              LABELS ARE SPECIFIED ON THE TYPE 12 CARDS.               -
CN                                                                      -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          REPROCESSING PLANT OUTPUT INITIAL COMPOSITION (TYPE 23)     -
```

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C                                                                       -
CL    FORMAT-----(I2,4X,A6,6X,3(A6,E12.5))                              -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     23                                                      -
CD                                                                      -
CD  2   7-12    REPROCESSING PLANT LABEL (REPEATED ON ADDITIONAL         -
CD              CARDS, IF NECESSARY).                                   -
CD                                                                      -
CD  3   19-24   ACTIVE ISOTOPE LABEL.                                   -
CD                                                                      -
CD  4   25-36   ATOMIC DENSITY (ATOMS/CC * 1.0E-24).                    -
CD                                                                      -
CD  5   37-42   ACTIVE ISOTOPE LABEL.                                   -
CD                                                                      -
CD  6   43-54   ATOMIC DENSITY (ATOMS/CC * 1.0E-24).                    -
CD                                                                      -
CD  7   55-60   ACTIVE ISOTOPE LABEL.                                   -
CD                                                                      -
CD  8   61-72   ATOMIC DENSITY (ATOMS/CC * 1.0E-24).                    -
C                                                                       -
CN              THE TYPE 23 CARDS SHOULD NOT BE SUPPLIED IF THE DATA    -
CN              MANAGEMENT IS SPECIFIED USING THE TYPE 35 CARDS.        -
CN                                                                      -
CN              ALL ACTIVE ISOTOPE LABELS MUST BE DEFINED ON            -
CN              TYPE 09 CARDS OR VIA A PRESTORED BURNUP CHAIN.          -
CN                                                                      -
CN              CARD TYPE 23 IS PROVIDED ONLY IF IT IS DESIRED TO       -
CN              SPECIFY THE COMPOSITION OF THE REPROCESSING PLANT       -
CN              OUTPUT STORAGE AT THE START OF THE PROBLEM. IF CARD     -
CN              TYPE 23 IS GIVEN, COLS. 37-48 ON CARD TYPE 16 MUST      -
CN              SPECIFY THE VOLUME OF THE REPROCESSING PLANT OUTPUT.    -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          ACTIVE ISOTOPE DESCRIPTIONS (TYPE 24)                       -
C                                                                       -
CL    FORMAT-----(I2,4X,2(A6,I6,6X,E12.5))                              -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     24                                                      -
CD                                                                      -
CD  2   7-12    ACTIVE ISOTOPE LABEL.                                   -
CD                                                                      -
CD  3   13-18   FISSILE BREEDING RATIO FLAG                             -
CD                                                                      -
CD  4   25-36   ATOMIC MASS (DEFAULT OBTAINED FROM DATA SET ISOTXS).    -
CD                                                                      -
CD  5   37-42   ACTIVE ISOTOPE LABEL.                                   -
CD                                                                      -
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CD  6   43-48   FISSILE BREEDING RATIO FLAG                              -
CD                                                                      -
CD  7   55-66   ATOMIC MASS (DEFAULT OBTAINED FROM DATA SET ISOTXS).    -
C                                                                       -
CN              ACTIVE ISOTOPE LABELS MUST BE DEFINED ON TYPE 09        -
CN              CARDS OR VIA A PRESTORED BURNUP CHAIN AND AT LEAST      -
CN              ONE OF THESE MUST ALSO APPEAR ON A TYPE 24 CARD ON      -
CN              WHICH A 1 APPEARS IN COLS. 13-18 OR 43-48.              -
CN              THE FISSILE BREEDING RATIO FLAG MUST BE EQUAL TO "1"    -
CN              FOR FISSILE ISOTOPES INCLUDED IN THE CALCULATION OF     -
CN              CONVERSION AND BREEDING RATIOS, AND "0" OTHERWISE.      -
CN                                                                      -
CN                                    PRODUCTION OF FISSILE ATOMS       -
CN                   BREEDING RATIO = ----------------------------      -
CN                                    DESTRUCTION OF FISSILE ATOMS      -
CN                                                                      -
CN              IN REBUS-3, AVOGADRO'S NUMBER = 0.6022054E24 UNLESS     -
CN              OVERRIDDEN VIA THE DATA SET A.BURN TYPE 28 CARD DATA.   -
CN              ATOMIC MASSES SHOULD BE CONSISTENT WITH THE VALUE OF    -
CN              AVOGADRO'S NUMBER.                                      -
CN                                                                      -
CN              IF THE ATOMIC MASS AS OBTAINED FROM DATA SET ISOTXS     -
CN              HAS THE VALUE 0.0, THE MASS IS CHANGED TO 1.0.          -
CN              USERS SHOULD BE AWARE THAT ARTIFICIAL ISOTOPES SUCH AS  -
CN              LUMPED FISSION PRODUCTS OR DUMMY ISOTOPES MAY HAVE      -
CN              UNREALISTIC MASSES IN DATA SET ISOTXS.  THE TYPE 24     -
CN              CARDS MAY BE USED TO PROVIDE MORE REALISTIC VALUES FOR  -
CN              THE MASSES OF SUCH ISOTOPES.                            -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          ACTIVE ISOTOPE DECAY CONSTANTS (TYPE 25)                    -
C                                                                       -
CL    FORMAT-----(I2,4X,A6,I6,3(A6,E12.5))                              -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     25                                                      -
CD                                                                      -
CD  2   7-12    LABEL OF ACTIVE ISOTOPE UNDERGOING REACTION (REPEATED    -
CD              ON ALL CARDS THAT SPECIFY OTHER REACTIONS FOR            -
CD              THIS ISOTOPE).                                          -
CD                                                                      -
CD  3   13-18   REACTION TYPE (REPEATED ON ADDITIONAL CARDS, IF         -
CD              NECESSARY; THE SAME AS ON CARD TYPE 09).                -
CD              6...BETA-MINUS DECAY.                                   -
CD              7...BETA-PLUS DECAY.                                    -
CD              8...ALPHA DECAY.                                        -
CD                                                                      -
CD  4   19-24   LABEL OF PRODUCT ISOTOPE FROM THE REACTION SPECIFIED    -
CD              IN COLS. 13-18 OR THE PRIVILEGED LABEL DELETE.          -
CD                                                                      -
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CD  5   25-36   DECAY CONSTANT (1/SEC) FOR THE ISOTOPE SPECIFIED IN    -
CD              COLS. 19-24.                                          -
CD                                                                    -
CD  6   37-42   LABEL OF PRODUCT ISOTOPE FROM THE REACTION SPECIFIED   -
CD              IN COLS. 13-18 OR THE PRIVILEGED LABEL DELETE.        -
CD                                                                    -
CD  7   43-54   DECAY CONSTANT (1/SEC) FOR THE ISOTOPE SPECIFIED IN    -
CD              COLS. 19-24.                                          -
CD                                                                    -
CD  8   55-60   LABEL OF PRODUCT ISOTOPE FROM THE REACTION SPECIFIED   -
CD              IN COLS. 13-18 OR THE PRIVILEGED LABEL DELETE.        -
CD                                                                    -
CD  9   61-72   DECAY CONSTANT (1/SEC) FOR THE ISOTOPE SPECIFIED IN    -
CD              COLS. 19-24.                                          -
C                                                                     -
CN              A TYPE 25 CARD IS REQUIRED FOR EACH ISOTOPE WHICH HAS  -
CN              A REACTION TYPE 6-8 SPECIFIED IN COLS. 13-18 ON A TYPE -
CN              09 CARD.  TYPE 25 CARDS NEED NOT BE SUPPLIED FOR       -
CN              ISOTOPES IN PRESTORED BURNUP CHAINS (SEE CARD TYPE 09) -
CN              UNLESS IT IS DESIRED TO OVERRIDE THE DEFAULT           -
CN              DECAY CONSTANTS FOR ANY OF THE ISOTOPES IN THE         -
CN              PRESTORED CHAINS.  IF A TYPE 09 CARD WAS SUPPLIED WITH -
CN              THE PRIVILEGED LABEL DELETE IN COLS. 19-24 FOR AN      -
CN              ACTIVE ISOTOPE HAVING A REACTION TYPE 6, 7, OR 8, A    -
CN              CORRESPONDING TYPE 25 CARD MUST BE SUPPLIED            -
CN              WHICH SIMILARLY HAS DELETE IN COLS. 19-24 FOR THE      -
CN              SAME ACTIVE ISOTOPE AND REACTION TYPE IN COLS. 7-12    -
CN              AND 13-18 RESPECTIVELY.  IF A TYPE 25 CARD HAS THE     -
CN              PRIVILEGED LABEL DELETE IN COLS 19-24, THE REST OF THE -
CN              DATA ON THAT TYPE 25 CARD WILL BE IGNORED.             -
C                                                                     -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          ISOTOPES HAVING BURNUP DEPENDENT CROSS SECTIONS (TYPE 26)  -
C                                                                     -
CL    FORMAT-----(I2,4X,A6,10A6)                                      -
C                                                                     -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY               -
CD  =  =======  ========================================================-
CD  1   1-2     26                                                    -
CD                                                                    -
CD  2   7-12    LABEL OF REFERENCE BASE ISOTOPE.                       -
CD                                                                    -
CD  3   13-18   LABEL OF THE ISOTOPE WHOSE CROSS SECTIONS ARE TO BE    -
CD              VARIED AS A FUNCTION OF THE ATOMIC DENSITY OF THE      -
CD              REFERENCE BASE ISOTOPE SPECIFIED IN COLS. 7-12.        -
CD                                                                    -
CD  4   19-24   LABEL OF THE ISOTOPE WHOSE CROSS SECTIONS ARE TO BE    -
CD              VARIED AS A FUNCTION OF THE ATOMIC DENSITY OF THE      -
CD              REFERENCE BASE ISOTOPE SPECIFIED IN COLS. 7-12.        -
CD                                                                    -
CD  5   25-30   LABEL OF THE ISOTOPE WHOSE CROSS SECTIONS ARE TO BE    -
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CD                VARIED AS A FUNCTION OF THE ATOMIC DENSITY OF THE      -
CD                REFERENCE BASE ISOTOPE SPECIFIED IN COLS. 7-12.        -
CD                                                                       -
CD  6    31-36    LABEL OF THE ISOTOPE WHOSE CROSS SECTIONS ARE TO BE    -
CD                VARIED AS A FUNCTION OF THE ATOMIC DENSITY OF THE      -
CD                REFERENCE BASE ISOTOPE SPECIFIED IN COLS. 7-12.        -
CD                                                                       -
CD  7    37-42    LABEL OF THE ISOTOPE WHOSE CROSS SECTIONS ARE TO BE    -
CD                VARIED AS A FUNCTION OF THE ATOMIC DENSITY OF THE      -
CD                REFERENCE BASE ISOTOPE SPECIFIED IN COLS. 7-12.        -
CD                                                                       -
CD  8    43-48    LABEL OF THE ISOTOPE WHOSE CROSS SECTIONS ARE TO BE    -
CD                VARIED AS A FUNCTION OF THE ATOMIC DENSITY OF THE      -
CD                REFERENCE BASE ISOTOPE SPECIFIED IN COLS. 7-12.        -
CD                                                                       -
CD  9    49-54    LABEL OF THE ISOTOPE WHOSE CROSS SECTIONS ARE TO BE    -
CD                VARIED AS A FUNCTION OF THE ATOMIC DENSITY OF THE      -
CD                REFERENCE BASE ISOTOPE SPECIFIED IN COLS. 7-12.        -
CD                                                                       -
CD  10   55-60    LABEL OF THE ISOTOPE WHOSE CROSS SECTIONS ARE TO BE    -
CD                VARIED AS A FUNCTION OF THE ATOMIC DENSITY OF THE      -
CD                REFERENCE BASE ISOTOPE SPECIFIED IN COLS. 7-12.        -
CD                                                                       -
CD  11   61-66    LABEL OF THE ISOTOPE WHOSE CROSS SECTIONS ARE TO BE    -
CD                VARIED AS A FUNCTION OF THE ATOMIC DENSITY OF THE      -
CD                REFERENCE BASE ISOTOPE SPECIFIED IN COLS. 7-12.        -
CD                                                                       -
CD  12   67-72    LABEL OF THE ISOTOPE WHOSE CROSS SECTIONS ARE TO BE    -
CD                VARIED AS A FUNCTION OF THE ATOMIC DENSITY OF THE      -
CD                REFERENCE BASE ISOTOPE SPECIFIED IN COLS. 7-12.        -
C                                                                        -
CN                TYPE 26 CARDS ARE TO BE PROVIDED ONLY IF IT IS DESIRED -
CN                TO USE BURNUP-DEPENDENT CROSS SECTIONS IN A PROBLEM.   -
CN                                                                       -
CN                EACH ISOTOPE APPEARING ON A TYPE 26 CARD MUST ALSO BE  -
CN                SPECIFIED ON A TYPE 10 OR 09 CARD AND ON A TYPE 13     -
CN                AND/OR 14 CARD OF DATA SET A.NIP3.  THAT IS, THE       -
CN                ISOTOPES SPECIFIED ON THE TYPE 26 CARDS ARE THOSE WHICH-
CN                ARE INCLUDED IN THE REBUS-3 CALCULATION.               -
CN                                                                       -
CN                NORMALLY, DIFFERENT REFERENCE BASE ISOTOPES WOULD      -
CN                BE SPECIFIED FOR DIFFERENT REGIONS OF THE REACTOR      -
CN                BEING CALCULATED.  THUS, E.G., U235I MIGHT BE USED FOR -
CN                THE BASE ISOTOPE IN AN INNER CORE, U235O IN AN OUTER   -
CN                CORE REGION, AND PU239B IN A RADIAL BLANKET WHICH WAS  -
CN                INITIALLY FUELED WITH DEPLETED URANIUM.  IN THE FIRST  -
CN                CASE, THE U235I AND U235O DENSITIES WOULD DECREASE     -
CN                WITH TIME WHEREAS IN THE LATTER CASE, THE PU239B        -
CN                DENSITY WOULD INCREASE IN CONCENTRATION WITH TIME.      -
CN                                                                       -
CN                ISOTOPES WHICH ARE REPEATED IN COLS. 13-72 ON A GIVEN  -
CN                TYPE 26 CARD WILL BE IGNORED AS WILL ISOTOPES WHICH ARE-
CN                REPEATED ON SUBSEQUENT TYPE 26 CARDS.  THUS, IF ONE    -
CN                SUPPLIED                                               -
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CN                                                                      -
CN              26 U25I1 U25I1 U28I1 U25I1                              -
CN              26 U28I1 U25I1 U28I1                                    -
CN                                                                      -
CN              THE RESULT WOULD BE THE SAME AS IF ONE HAD SUPPLIED     -
CN                                                                      -
CN              26 U25I1 U25I1 U28I1                                    -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          END-OF-CYCLE KEFF SEARCH DATA (TYPE 27)                     -
C                                                                       -
CL    FORMAT-----(I2,10X,3E12.5)                                        -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     27                                                      -
CD                                                                      -
CD  2   13-24   DESIRED END-OF-CYCLE KEFF, KEFF(EOC). (DEFAULT=1.0)     -
CD                                                                      -
CD  3   25-36   CONVERGENCE CRITERION, EPSD: RELATIVE ERROR ALLOWABLE   -
CD              IN KEFF(EOC).  FOR CONVERGENCE OF END-OF-CYCLE          -
CD              KEFF SEARCH.  (DEFAULT=0.001)                           -
CD                                                                      -
CD  4   37-48   SECOND BURN CYCLE TIME GUESS FOR END-OF-CYCLE KEFF      -
CD              SEARCH.  (DEFAULT=INITIAL BURN CYCLE TIME GUESS FROM    -
CD              COLS. 37-48 OF CARD TYPE 03 PLUS 10 PER CENT)           -
C                                                                       -
CN              IF A TYPE 27 CARD IS INCLUDED IN THE INPUT DATA, THE    -
CN              REACTOR BURN CYCLE TIME WILL BE ADJUSTED TO ACHIEVE     -
CN              THE SPECIFIED END-OF-CYCLE KEFF.  CARD TYPE 04 (AND     -
CN              ASSOCIATED EXTERNAL CYCLE CARDS) MUST BE PRESENT IN     -
CN              THE INPUT DATA IF AN END-OF-CYCLE KEFF SEARCH IS TO     -
CN              BE DONE.  HOWEVER, AN ENRICHMENT SEARCH AND/OR A        -
CN              BURNUP SEARCH CANNOT BE PERFORMED SIMULTANEOUSLY WITH   -
CN              AN KEFF(EOC) SEARCH.  THEREFORE, IF A TYPE 27 CARD IS   -
CN              PRESENT IN THE INPUT DATA, THE ENRICHMENT AND BURNUP    -
CN              CONVERGENCE CRITERIA (EPSF AND EPSG FROM CARD TYPES 04  -
CN              AND 03 RESPECTIVELY) MUST BE SPECIFIED AS 1.0 OR        -
CN              LARGER.                                                 -
CN                                                                      -
CN              USERS SHOULD BE CAREFUL TO SPECIFY THE DESIRED CHARGE   -
CN              SEARCH PARAMETER ON THE TYPE 04 CARD IN COLS. 49-60.    -
CN                                                                      -
CN              NOTE THAT PROBLEMS INVOLVING MEDIUM-TO-HIGH DISCHARGE   -
CN              BURNUP (GREATER THAN ABOUT 20 ATOM PER CENT) WILL       -
CN              REQUIRE AT LEAST 2 CYCLIC MODE ITERATIONS IN ORDER TO   -
CN              INSURE CONVERGED EOC EIGENVALUES. (SEE CARD TYPE 02).   -
C                                                                       -
C-----------------------------------------------------------------------
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C-----------------------------------------------------------------------
CR          AVOGADRO'S NUMBER (TYPE 28)                                -
C                                                                      -
CL    FORMAT-----(I2,10X,E12.5)                                        -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     28                                                     -
CD                                                                     -
CD  2   13-24   AVAGADRO'S NUMBER (DEFAULT=0.6022054 E+24)             -
C                                                                      -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          SUMMARY EDITS AREA SPECIFICATIONS (TYPE 29)                -
C                                                                      -
CL    FORMAT-----(I2,4X,10A6)                                          -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     29                                                     -
CD                                                                     -
CD  2   7-12    AREA LABEL CORRESPONDING TO THE INNER CORE.             -
CD              (DEFAULT=ICORE)                                        -
CD                                                                     -
CD  3   13-18   AREA LABEL CORRESPONDING TO THE MIDDLE CORE.           -
CD              (DEFAULT=MCORE)                                        -
CD                                                                     -
CD  4   19-24   AREA LABEL CORRESPONDING TO THE OUTER CORE.            -
CD              (DEFAULT=OCORE)                                        -
CD                                                                     -
CD  5   25-30   AREA LABEL CORRESPONDING TO THE INNER BLANKET.         -
CD              (DEFAULT=IBLKT)                                        -
CD                                                                     -
CD  6   31-36   AREA LABEL CORRESPONDING TO THE MIDDLE BLANKET.        -
CD              (DEFAULT=MBLKT)                                        -
CD                                                                     -
CD  7   37-42   AREA LABEL CORRESPONDING TO THE OUTER BLANKET.         -
CD              (DEFAULT=OBLKT)                                        -
CD                                                                     -
CD  8   43-48   AREA LABEL CORRESPONDING TO THE RADIAL BLANKET.        -
CD              (DEFAULT=RBLKT)                                        -
CD                                                                     -
CD  9   49-54   AREA LABEL CORRESPONDING TO THE AXIAL BLANKET.         -
CD              (DEFAULT=ABLKT)                                        -
CD                                                                     -
CD  10  55-60   AREA LABEL CORRESPONDING TO THE CONTROL RODS.          -
CD              (DEFAULT=CONTRL)                                       -
CD                                                                     -
CD  11  61-66   AREA LABEL CORRESPONDING TO THE OUTER RADIAL BLANKET.  -
CD              (DEFAULT=ORBLKT)                                       -
C                                                                      -
CN              TYPE 29 CARD DATA INDICATE THE CORRESPONDENCE BETWEEN  -
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CN              THE AREA LABELS ON THE DATA SET A.NIP3 TYPE 07 CARDS   -
CN              AND THE VARIOUS PORTIONS OF THE REACTOR.  MASS BALANCE -
CN              WILL BE PROVIDED FOR THE INNER CORE+MIDDLE CORE+OUTER  -
CN              CORE, INNER BLANKET+MIDDLE BLANKET+OUTER BLANKET,      -
CN              RADIAL BLANKET, AXIAL BLANKET, AND OUTER RADIAL        -
CN              BLANKET.                                               -
C                                                                      -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          SUMMARY MASS BALANCE ISOTOPE SPECIFICATIONS (TYPE 30)      -
C                                                                      -
CL    FORMAT-----(I2,4X,5(I6,A6))                                      -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     30                                                     -
CD                                                                     -
CD  2   7-12    ACTIVE ISOTOPE NUMBER.                                 -
CD                                                                     -
CD  3   13-18   ACTIVE ISOTOPE LABEL.                                  -
CD                                                                     -
CD  4   19-24   ACTIVE ISOTOPE NUMBER.                                 -
CD                                                                     -
CD  5   25-30   ACTIVE ISOTOPE LABEL.                                  -
CD                                                                     -
CD  6   31-36   ACTIVE ISOTOPE NUMBER.                                 -
CD                                                                     -
CD  7   37-42   ACTIVE ISOTOPE LABEL.                                  -
CD                                                                     -
CD  8   43-48   ACTIVE ISOTOPE NUMBER.                                 -
CD                                                                     -
CD  9   49-54   ACTIVE ISOTOPE LABEL.                                  -
CD                                                                     -
CD  10  55-60   ACTIVE ISOTOPE NUMBER.                                 -
CD                                                                     -
CD  11  60-66   ACTIVE ISOTOPE LABEL.                                  -
C                                                                      -
CN              NOTE THAT THE ISOTOPE LABELS MAY CORRESPOND TO EITHER  -
CN              THE FIVE LEFTMOST CHARACTERS OF THE ENDF/B ABSOLUTE    -
CN              ISOTOPE LABEL OR TO THE LABELS ON THE TYPE 09 CARDS.   -
CN                                                                     -
CN              TYPE 30 CARD DATA INDICATE THE ABSOLUTE LABELS FOR THE -
CN              22 ACTIVE ISOTOPES WHICH ARE INCLUDED IN THE SUMMARY   -
CN              MASS BALANCE EDITS.  THE DEFAULT LABELS CORRESPONDING  -
CN              TO THE 22 ISOTOPES ARE AS LISTED BELOW.                -
CN                     1...TH232                                       -
CN                     2...PA233                                       -
CN                     3...U-233                                       -
CN                     4...U-234                                       -
CN                     5...U-235                                       -
CN                     6...U-236                                       -
CN                     7...U-238                                       -
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CN                      8...NP237                                          -
CN                      9...PU236                                          -
CN                     10...PU238                                          -
CN                     11...PU239                                          -
CN                     12...PU240                                          -
CN                     13...PU241                                          -
CN                     14...PU242                                          -
CN                     15...AM241                                          -
CN                     16...AM242                                          -
CN                     17...AM243                                          -
CN                     18...CM242                                          -
CN                     19...CM243                                          -
CN                     20...CM244                                          -
CN                     21...CM245                                          -
CN                     22...CM246                                          -
CN                                                                         -
CN              IF THE ISOTXS DATA SET BEING USED HAD U235 AS THE          -
CN              ABSOLUTE ISOTOPE LABEL FOR URANIUM 235 ISOTOPES IN THE     -
CN              SET, THE USER WOULD HAVE TO SUPPLY A TYPE 30 CARD WITH     -
CN                   30  5  U235                                          -
CN              (IN FREE FORMAT INPUT) TO ASSURE THAT THE URANIUM 235      -
CN              MASSES WERE INCLUDED IN THE SUMMARY EDITS.                 -
CN                                                                         -
CN              NOTE THAT IF SPECIAL ISOTOPES ARE TREATED AS ACTIVE        -
CN              ISOTOPES, THEY CAN BE INCLUDED IN PLACE OF ONE OF THE      -
CN              ABOVE 22 STANDARD ISOTOPES.  FOR EXAMPLE, IF BORON 10      -
CN              WERE AN ACTIVE ISOTOPE AND THE PROBLEM CONTAINED NO        -
CN              THORIUM, ONE MIGHT INPUT A TYPE 30 CARD AS                 -
CN                   30  1  B-10                                          -
CN              IN WHICH CASE THE MASS EDIT FOR BORON 10 WILL APPEAR       -
CN              IN THE POSITION WHERE THORIUM NORMALLY APPEARS.            -
CN              HOWEVER, IN THIS CASE, B-10 WOULD BE THEN BE INCLUDED      -
CN              IN THE TOTAL HEAVY METAL EDIT.                             -
C                                                                          -
C-------------------------------------------------------------------------


C-------------------------------------------------------------------------
CR          SUMMARY NEUTRON BALANCE ISOTOPE SPECIFICATIONS (TYPE 31)       -
C                                                                          -
CL    FORMAT-----(I2,4X,I6,10A6)                                           -
C                                                                          -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                    -
CD  =  =======  ========================================================-
CD  1   1-2     31                                                         -
CD                                                                         -
CD  2   7-12    ISOTOPE CLASSIFICATION.                                    -
CD                                                                         -
CD  3   13-18   ISOTOPE ABSOLUTE OR UNIQUE LABEL                           -
CD                                                                         -
CD  4   19-24   ISOTOPE ABSOLUTE OR UNIQUE LABEL                           -
CD                                                                         -
CD  5   25-30   ISOTOPE ABSOLUTE OR UNIQUE LABEL                           -
CD                                                                         -
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CD  6   31-36   ISOTOPE ABSOLUTE OR UNIQUE LABEL.                        -
CD                                                                      -
CD  7   37-42   ISOTOPE ABSOLUTE OR UNIQUE LABEL                        -
CD                                                                      -
CD  8   43-48   ISOTOPE ABSOLUTE OR UNIQUE LABEL.                       -
CD                                                                      -
CD  9   49-54   ISOTOPE ABSOLUTE OR UNIQUE LABEL                        -
CD                                                                      -
CD  10  55-60   ISOTOPE ABSOLUTE OR UNIQUE LABEL.                       -
CD                                                                      -
CD  11  61-66   ISOTOPE ABSOLUTE OR UNIQUE LABEL                        -
CD                                                                      -
CD  12  67-72   ISOTOPE ABSOLUTE OR UNIQUE LABEL                        -
C                                                                       -
CN              IF NO TYPE 31 CARDS ARE SUPPLIED, THE DATA SUPPLIED     -
CN              ON THE TYPE 04 CARDS OF DATA SET A.SUMMAR WILL BE USED  -
CN              IF PROVIDED.                                            -
CN                                                                      -
CN              THE TYPE 31 CARDS INDICATE THE CLASSIFICATION OF THE    -
CN              ISOTOPES IN THE PROBLEM.  COLS. 7-12 CORRESPOND TO      -
CN              THE FOLLOWING TABLE.                                    -
CN                                                                      -
CN                    ISOTOPE CLASSIFICATION                            -
CN                         1...FISSILE                                  -
CN                         2...FERTILE                                  -
CN                         3...OTHER ACTINIDE                           -
CN                         4...FISSION PRODUCT                          -
CN                         5...STRUCTURE                                -
CN                         6...COOLANT                                  -
CN                         7...CONTROL                                  -
CN                         8...UNDEFINED                                -
CN                         9...SPECIAL                                  -
CN                                                                      -
CN              NOTE THAT THE ISOTOPE ABSOLUTE LABELS CORRESPOND TO     -
CN              THE FIVE LEFTMOST CHARACTERS OF THE ENDF/B ABSOLUTE     -
CN              ISOTOPE LABEL.                                          -
CN                                                                      -
CN              IF AN ISOTOPE LABEL IN COLS. 13-72 CORRESPONDS TO AN    -
CN              ENDF/B ABSOLUTE ISOTOPE LABEL, THEN ALL ISOTOPES IN     -
CN              THE PROBLEM HAVING THAT ABSOLUTE LABEL WILL BE GIVEN    -
CN              THE CLASSIFICATION SPECIFIED IN COLS. 7-12.  IF AN      -
CN              ISOTOPE LABEL CORRESPONDS TO A UNIQUE ISOTOPE LABEL,    -
CN              THEN ONLY THAT UNIQUE ISOTOPE IN THE PROBLEM WILL       -
CN              BE GIVEN THE SPECIFIED CLASSIFICATION AND ALL OTHER     -
CN              ISOTOPES HAVING THE SAME ABSOLUTE LABEL AS THAT OF THE  -
CN              SPECIFIED UNIQUE ISOTOPE LABEL WILL BE GIVEN DEFAULT    -
CN              CLASSIFICATIONS.  ISOTOPES WHICH ARE NOT SPECIFIED      -
CN              ON THE TYPE 31 CARDS WILL BE GIVEN DEFAULT              -
CN              CLASSIFICATIONS ACCORDING TO THEIR ABSOLUTE LABELS.     -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
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CR          SUMMARY MASS FLOW SPECIFICATIONS 1 (TYPE 32)                -
C                                                                       -
CL    FORMAT-----(I2,4X,4E12.6,2I6)                                     -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     32                                                      -
CD                                                                      -
CD  2   7-18    EMW, MEGAWATTS ELECTRIC. (DEFAULT=1000.0)               -
CD                                                                      -
CD  3   19-30   THMW, MEGAWATTS THERMAL. (DEFAULT=2740.0)               -
CD                                                                      -
CD  4   31-42   CF, CAPACITY FACTOR IN PER CENT. (DEFAULT=0.75)         -
CD                                                                      -
CD  5   43-54   FPD, CYCLE LENGTH IN FULL POWER DAYS. (DEFAULT=273.75)  -
CD                                                                      -
CD  6   55-60   NPOW, RATIO OF ACTUAL POWER TO POWER USED FOR MASS      -
CD              FLOW CALCULATION. (DEFAULT=2)                           -
CD                                                                      -
CD  7   61-66   NZONE, NUMBER OF REACTOR ZONES.  NZONE=3 IF THERE ARE   -
CD              NO INTERNAL BLANKETS, OR 4 IF THERE ARE INTERNAL        -
CD              BLANKETS. (DEFAULT=3)                                   -
C                                                                       -
CN              NPOW IN COLS. 55-60 IS USED TO ACCOUNT FOR THE SYMMETRY-
CN              INVOLVED IN THE NEUTRONICS CALCULATION.  THUS, E.G.,    -
CN              IF ONLY HALF OF THE REACTOR IS BEING CALCULATED, THE    -
CN              HEAVY METAL INVENTORY MUST BE MULTIPLIED BY 2 SINCE     -
CN              THE THMW SPECIFIED FOR THE NEUTRONICS CALCULATION       -
CN              CORRESPONDS TO THE FULL POWER FOR THE COMPLETE REACTOR.-
CN                                                                      -
CN              IF THE TYPE 32 CARD IS SUPPLIED, BLANK FIELDS WILL      -
CN              CORRESPOND TO 0.0 OR 0 ACCORDING TO THE TYPE OF DATA    -
CN              TO BE SUPPLIED.  THE DEFAULT VALUES WILL APPLY ONLY IF  -
CN              THE TYPE 32 CARD IS NOT PROVIDED.                       -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          SUMMARY MASS FLOW SPECIFICATIONS 2 (TYPE 33)                -
C                                                                       -
CL    FORMAT-----(I2,4X,3E12.6,I6,A6)                                   -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     33                                                      -
CD                                                                      -
CD  2   7-18    EXT, EXTERNAL CYCLE TIME IN CALENDAR YEARS.              -
CD              (DEFAULT=1.0)                                           -
CD                                                                      -
CD  3   19-30   FLOSS, FRACTIONAL LOSS IN REPROCESSING. (DEFAULT=0.02)  -
CD                                                                      -
CD  4   31-42   EU235, U-235 FRACTION IN FERTILE URANIUM.               -
CD              (DEFAULT=0.002)                                         -
```

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CD                                                                      -
CD  5   43-48   NFIS, FISSILE DEFINITION FLAG.  0...U-235 NOT          -
CD              INCLUDED IN FISSILE DEFINITION, 1...U-235 INCLUDED     -
CD              IN FISSILE DEFINITION.  (DEFAULT=1)                    -
CD                                                                      -
CD  6   49-54   CFEED, LABEL OF EXTERNAL FEED SOURCE FOR THE CORE      -
C                                                                       -
CN              IF THE TYPE 33 CARD IS SUPPLIED, BLANK FIELDS WILL     -
CN              CORRESPOND TO 0.0 OR 0 ACCORDING TO THE TYPE OF DATA   -
CN              TO BE SUPPLIED.  THE DEFAULT VALUES WILL APPLY ONLY IF -
CN              THE TYPE 33 CARD IS NOT PROVIDED.                      -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          SUMMARY MASS FLOW SPECIFICATIONS 3 (TYPE 34)                -
C                                                                       -
CL    FORMAT-----(I2,4X,7I6)                                            -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     34                                                      -
CD                                                                      -
CD  2   7-12    NC, CORE RESIDENCE IN NUMBER OF CYCLES. (DEFAULT=1)     -
CD                                                                      -
CD  3   13-18   NRB, RADIAL BLANKET RESIDENCE IN NUMBER OF CYCLES.      -
CD                   (DEFAULT=5)                                        -
CD                                                                      -
CD  4   19-24   NIB, INNER BLANKET RESIDENCE IN NUMBER OF CYCLES.       -
CD                   (DEFAULT=0)                                        -
CD                                                                      -
CD  5   25-30   NFERAB, FERTILE MATERIAL TYPE IN THE AXIAL BLANKET.     -
CD                     0...URANIUM, 1...THORIUM. (DEFAULT=0)            -
CD                                                                      -
CD  6   31-36   NFERRB, FERTILE MATERIAL TYPE IN THE RADIAL BLANKET.    -
CD                     0...URANIUM, 1...THORIUM. (DEFAULT=0)            -
CD                                                                      -
CD  7   37-42   NFERIB, FERTILE MATERIAL TYPE IN THE INNER BLANKET.     -
CD                     0...URANIUM, 1...THORIUM. (DEFAULT=0)            -
CD                                                                      -
CD  8   43-48   NORB, OUTER RADIAL BLANKET RESIDENCE IN NUMBER OF       -
CD              CYCLES. (DEFAULT=0)                                     -
C                                                                       -
CN              IF AN OUTER RADIAL BLANKET IS INCLUDED, NFERRB          -
CN              SPECIFIED IN COLS. 31-36 WILL APPLY TO BOTH THE INNER   -
CN              AND OUTER PORTIONS OF THE RADIAL BLANKET ALTHOUGH EACH  -
CN              MAY HAVE A DISTINCT RESIDENCE TIME AS SPECIFIED BY NRB  -
CN              IN COLS. 13-18 AND NORB IN COLS. 43-48.                 -
CN                                                                      -
CN              IF THE TYPE 34 CARD IS SUPPLIED, BLANK FIELDS WILL      -
CN              CORRESPOND TO 0.  THE DEFAULT VALUES WILL APPLY ONLY    -
CN              IF THE TYPE 34 CARD IS NOT PROVIDED.                    -
C                                                                       -
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C-------------------------------------------------------------------------

C-------------------------------------------------------------------------
CR          GENERAL FUEL MANAGEMENT SPECIFICATIONS (TYPE 35)             -
C                                                                        -
CL    FORMAT-----(I2,4X,A6,A6,3(A6,2I6))                                 -
C                                                                        -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                  -
CD  =  =======  ========================================================-
CD  1   1-2     35                                                       -
CD                                                                       -
CD  2   7-12    PATH LABEL (REPEATED ON ADDITIONAL CARDS, IF              -
CD              NECESSARY).                                              -
CD                                                                       -
CD  3   13-18   PRIMARY COMPOSITION (ZONE) OR SECONDARY COMPOSITION      -
CD              (SUB-ZONE) LABEL                                         -
CD                                                                       -
CD  4   19-24   REGION LABEL OR FUEL MANAGEMENT GROUP LABEL OR           -
CD              PRIMARY COMPOSITION (ZONE) LABEL.                        -
CD                                                                       -
CD  5   25-30   BEGINNING STAGE NUMBER FOR WHICH THE COMPOSITION         -
CD              SPECIFIED IN COLS. 13-18 RESIDES IN THE REGION OR ZONE -
CD              SPECIFIED IN COLS. 19-24.                                -
CD                                                                       -
CD  6   31-36   ENDING STAGE NUMBER FOR WHICH THE COMPOSITION            -
CD              SPECIFIED IN COLS. 13-18 RESIDES IN THE REGION OR ZONE -
CD              SPECIFIED IN COLS. 19-24.                                -
CD                                                                       -
CD  7   37-42   REGION LABEL OR FUEL MANAGEMENT GROUP LABEL OR           -
CD              PRIMARY COMPOSITION (ZONE) LABEL.                        -
CD                                                                       -
CD  8   43-48   BEGINNING STAGE NUMBER FOR WHICH THE COMPOSITION         -
CD              SPECIFIED IN COLS. 13-18 RESIDES IN THE REGION OR ZONE -
CD              SPECIFIED IN COLS. 37-42.                                -
CD                                                                       -
CD  9   49-54   ENDING STAGE NUMBER FOR WHICH THE COMPOSITION            -
CD              SPECIFIED IN COLS. 13-18 RESIDES IN THE REGION OR ZONE -
CD              SPECIFIED IN COLS. 37-42.                                -
CD                                                                       -
CD  10  55-60   REGION LABEL OR FUEL MANAGEMENT GROUP LABEL OR           -
CD              PRIMARY COMPOSITION (ZONE) LABEL.                        -
CD                                                                       -
CD  11  61-66   BEGINNING STAGE NUMBER FOR WHICH THE COMPOSITION         -
CD              SPECIFIED IN COLS. 13-18 RESIDES IN THE REGION OR ZONE -
CD              SPECIFIED IN COLS. 55-60.                                -
CD                                                                       -
CD  12  67-72   ENDING STAGE NUMBER FOR WHICH THE COMPOSITION            -
CD              SPECIFIED IN COLS. 13-18 RESIDES IN THE REGION OR ZONE -
CD              SPECIFIED IN COLS. 55-60.                                -
C                                                                        -
CN              CARD TYPES 35, 36, AND 37 ARE PERTINENT ONLY TO          -
CN              NON-EQUILIBRIUM PROBLEMS.                                -
CN                                                                       -
CN              IF BOTH TYPE 11 AND 35 CARDS ARE PRESENT, THE TYPE 11    -
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CN              CARDS WILL BE IGNORED.                                  -
CN                                                                      -
CN              IF COLS. 31-36 AND/OR 49-54 AND/OR 67-72 ARE BLANK OR 0-
CN              THE ENDING STAGE NUMBER WILL BE SET EQUAL TO THE        -
CN              BEGINNING STAGE NUMBER SPECIFIED IN COLS. 25-30 AND/OR -
CN              43-48 AND/OR 61-66.                                     -
CN                                                                      -
CN              FOR A GIVEN PATH, COLS. 19-24, 37-42, AND 55-60 MUST    -
CN              EITHER BE ALL REGION LABELS, OR ALL FUEL MANAGEMENT      -
CN              LABELS, OR ALL PRIMARY COMPOSITION (ZONE LABELS).  SEE -
CN              CARD TYPE 45 FOR SPECIFICATION OF THE FUEL MANAGEMENT   -
CN              GROUPS.  IF ZONE LABELS ARE BEING USED, COLS. 13-18     -
CN              MUST CONTAIN A SUB-ZONE LABEL.  IF REGION (OR FUEL      -
CN              MANAGEMENT GROUP) LABELS ARE BEING USED, COLS. 13-18    -
CN              MUST CONTAIN A ZONE LABEL.                              -
CN                                                                      -
CN              IF ZONE LABELS OR FUEL MANAGEMENT GROUP LABELS ARE      -
CN              BEING USED TO DEFINE A PATH, COLS. 19-24, 37-42, AND    -
CN              55-60 MUST ALL CONTAIN THE SAME LABEL OR BE BLANK.      -
CN              THIS IS NECESSARY SINCE IT IS NOT POSSIBLE TO KNOW      -
CN              WHICH OF THE REGIONS ASSOCIATED WITH ONE OF THE STAGES -
CN              IS CONNECTED WITH A PARTICULAR REGION IN THE NEXT STAGE-
CN              IF THE FUEL IS BEING SHUFFLED.                          -
CN                                                                      -
CN              IN STAGE 1 OF EACH PATH, THE ZONE/REGION OR             -
CN              SUB-ZONE/ZONE CORRESPONDENCES MUST AGREE WITH THAT      -
CN              IMPLIED FROM THE DATA SET A.NIP3 TYPE 14/15 CARDS.      -
CN                                                                      -
CN              IF A NON-BLANK LABEL IS SPECIFIED IN COLS. 19-24,       -
CN              37-42, AND.OR 55-60, AND THE CORRESPONDING BEGINNING    -
CN              AND ENDING STAGE NUMBERS ARE BOTH 0, BOTH STAGE         -
CN              NUMBERS WILL BE SET EQUAL TO 1.                         -
CN                                                                      -
CN              STAGE NUMBERS MAY NOT OVERLAP IN A PARTICULAR PATH.     -
CN              THUS THE FOLLOWING DATA (IN FREE FIELD FORMAT) WOULD    -
CN              RESULT IN A FATAL INPUT ERROR...                        -
CN              35 C1 R1 1 4 R2 5 8 R3 3 3                              -
CN                                                                      -
CN              THE MATERIAL IDENTIFIED BY THE ZONE OR SUB-ZONE         -
CN              LABEL IN COLS. 13-18 CAN BE SENT TO TEMPORARY STORAGE   -
CN              BY LEAVING ITS DESTINATION (COLS. 19-24 AND/OR 37-42    -
CN              AND/OR 55-60) BLANK. THUS, IF COLS. 19-24 AND/OR 37-42 -
CN              AND/OR 55-60 ARE BLANK, THE ZONE OR SUB-ZONE            -
CN              SPECIFIED IN COLS. 13-18 WILL BE ASSUMED TO BE          -
CN              TEMPORARILY DISCHARGED FOR THE STAGES SPECIFIED IN      -
CN              COLS. 25-36 AND/OR 43-54 AND/OR 61-72.  NOTE HOWEVER,   -
CN              THE DESTINATION LABEL MAY NOT BE BLANK FOR STAGE 1.     -
CN                                                                      -
CN              THE PATH SPECIFIED IS NON-REPETITIVE SO THAT THE        -
CN              MATERIAL IDENTIFIED BY THE ZONE OR SUB-ZONE LABEL       -
CN              IN COLS. 13-18 WILL BE PERMANENTLY DISCHARGED AFTER     -
CN              THE LAST SPECIFIED STAGE.  HOWEVER, A PATH MAY BE       -
CN              REPEATED BY MEANS OF THE TYPE 37 CARDS.                 -
CN                                                                      -
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CN              IF THE SMALLEST BEGINNING STAGE NUMBER FOR A PARTICULAR-
CN              PATH IS GREATER THAN 1, COLS. 13-18 MUST CONTAIN A     -
CN              PRIMARY COMPOSITION (ZONE) LABEL, AND COLS. 19-24,     -
CN              37-42, AND 55-60 MUST CONTAIN REGION LABELS.  IN THIS  -
CN              CASE, IT WILL BE ASSUMED THAT THE MATERIAL IDENTIFIED  -
CN              BY THE ZONE LABEL IN COLS. 13-18 IS INTRODUCED AS      -
CN              FRESH FUEL AT THAT STAGE IN THE PATH.                  -
C                                                                      -
C---------------------------------------------------------------------

C---------------------------------------------------------------------
CR          GENERAL FUEL MANAGEMENT PARAMETERS (TYPE 36)               -
C                                                                      -
CL    FORMAT-----(I2,4X,3E12.5,3I6,E12.5)                              -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  =========================================================-
CD  1   1-2     36                                                     -
CD                                                                     -
CD  2   7-18    BURN CYCLE TIME (IN DAYS)                              -
CD                                                                     -
CD  3   19-30   SHUTDOWN TIME BETWEEN BURN CYCLES (IN DAYS)            -
CD                                                                     -
CD  4   31-42   RELATIVE REACTOR POWER (DEFAULT=1.0)                   -
CD                                                                     -
CD  5   43-48   BEGINNING STAGE NUMBER FOR WHICH THE ABOVE PARAMETERS  -
CD              APPLY                                                  -
CD                                                                     -
CD  6   49-54   ENDING STAGE NUMBER FOR WHICH THE ABOVE PARAMETERS     -
CD              APPLY                                                  -
CD                                                                     -
CD  7   55-60   NUMBER OF SUBINTERVALS INTO WHICH THE TOTAL BURN CYCLE -
CD              TIME IS TO BE DIVIDED (DEFAULT=1).                     -
CD                                                                     -
CD  8   61-72   DESIRED UNPOISONED KEFF(0)                            -
C                                                                      -
CN              THE DEFAULT BURN CYCLE TIME, SHUTDOWN TIME BETWEEN     -
CN              BURN CYCLES, AND NUMBER OF SUBINTERVALS FOR THE BURN   -
CN              STEP ARE SPECIFIED ON THE TYPE 03 CARD ABOVE. THE      -
CN              DEFAULT REACTOR POWER WILL BE WHATEVER WAS SPECIFIED   -
CN              FOR THE NEUTRONICS CALCULATION BEING USED.  THE DEFAULT-
CN              DESIRED UNPOISONED KEFF(0) IS SPECIFIED ON THE TYPE 04 -
CN              CARD ABOVE.                                            -
CN                                                                     -
CN              NOTE THAT THE FRACTION OF THE TOTAL BURN TIME AT       -
CN              WHICH KEFF(0) IS TO BE REACHED AS SPECIFIED ON THE     -
CN              TYPE 04 CARD ABOVE WILL BE USED FOR EACH OF THE BURN   -
CN              CYCLES.                                                -
CN                                                                     -
CN              STAGE 1 WILL ALWAYS USE THESE DATA REGARDLESS OF THE   -
CN              DATA SUPPLIED ON THE TYPE 36 CARDS.  FOR STAGES 2 AND  -
CN              LARGER, ANY STAGE NOT SPECIFIED ON THE TYPE 36 CARDS   -
CN              WILL USE THE DEFAULT VALUES INDICATED ABOVE.           -
CN                                                                     -
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CN              IF COLS. 49-54 ARE 0 OR BLANK, THE ENDING STAGE NUMBER -
CN              WILL BE SET EQUAL TO THE BEGINNING STAGE NUMBER        -
CN              SPECIFIED IN COLS 43-48.                               -
C                                                                      -
C---------------------------------------------------------------------

C---------------------------------------------------------------------
CR          GENERAL FUEL MANAGEMENT REPETITION FACTORS (TYPE 37)       -
C                                                                      -
CL    FORMAT-----(I2,4X,5(A6,I6))                                      -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     37                                                     -
CD                                                                     -
CD  2   7-12    PATH LABEL                                             -
CD                                                                     -
CD  3   13-18   NUMBER OF TIMES THE PATH SPECIFIED IN COLS. 7-12 IS    -
CD              TO BE REPEATED (DEFAULT=0)                             -
CD                                                                     -
CD  4   19-24   PATH LABEL                                             -
CD                                                                     -
CD  5   25-30   NUMBER OF TIMES THE PATH SPECIFIED IN COLS. 19-24 IS   -
CD              TO BE REPEATED (DEFAULT=0)                             -
CD                                                                     -
CD  6   31-36   PATH LABEL                                             -
CD                                                                     -
CD  7   37-42   NUMBER OF TIMES THE PATH SPECIFIED IN COLS. 31-36 IS   -
CD              TO BE REPEATED (DEFAULT=0)                             -
CD                                                                     -
CD  8   43-48   PATH LABEL                                             -
CD                                                                     -
CD  9   49-54   NUMBER OF TIMES THE PATH SPECIFIED IN COLS. 43-48 IS   -
CD              TO BE REPEATED (DEFAULT=0)                             -
CD                                                                     -
CD  10  55-60   PATH LABEL                                             -
CD                                                                     -
CD  11  61-66   NUMBER OF TIMES THE PATH SPECIFIED IN COLS. 55-60 IS   -
CD              TO BE REPEATED (DEFAULT=0)                             -
C                                                                      -
CN              THE TYPE 37 CARDS ARE PERTINENT ONLY IF TYPE 35 CARDS  -
CN              ARE PROVIDED.                                          -
CN                                                                     -
CN              AFTER COMPLETION OF A PATH AS SPECIFIED ON THE TYPE 35 -
CN              CARDS, IF THAT PATH IS ALSO SPECIFIED ON A TYPE 37     -
CN              CARD, IT WILL BE REPEATED AS MANY TIMES AS SPECIFIED   -
CN              BY THE TYPE 37 CARD DATA.                              -
C                                                                      -
C---------------------------------------------------------------------

C---------------------------------------------------------------------
CR          TIME DEPENDENT CONTROL ROD POSITIONS (TYPE 38)             -
C                                                                      -
CL    FORMAT-----(I2,4X,A6,4E12.5)                                     -
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C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     38                                                     -
CD                                                                     -
CD  2   7-12    CONTROL-ROD BANK LABEL (REPEATED ON ADDITIONAL          -
CD              TYPE 38 CARDS IF NECESSARY).                           -
CD                                                                     -
CD  3   13-24   TIME (DAYS).                                           -
CD                                                                     -
CD  4   25-36   AXIAL POSITION OF THE CONTROL-ROD BANK TIP AT THE      -
CD              TIME SPECIFIED IN COLS. 13-24 (CM).                    -
CD                                                                     -
CD  5   37-48   TIME (DAYS).                                           -
CD                                                                     -
CD  6   49-60   AXIAL POSITION OF THE CONTROL-ROD BANK TIP AT THE      -
CD              TIME SPECIFIED IN COLS. 37-48 (CM).                    -
C                                                                      -
CN              TYPE 38 CARDS MUST BE SUPPLIED IF CONTROL RODS HAVE    -
CN              BEEN SPECIFIED ON THE DATA SET A.NIP3 TYPE 44 CARDS.   -
CN                                                                     -
CN              THE CONTROL-ROD BANK LABELS IN COLS. 7-12 CORRESPOND TO-
CN              THE LABELS SPECIFIED IN COLS. 7-12 ON THE DATA SET     -
CN              A.NIP3 TYPE 44 CARDS.  IF ONLY ONE CONTROL-ROD BANK    -
CN              IS INVOLVED, COLS. 7-12 MAY BE BLANK.                  -
CN                                                                     -
CN              IF COLS. 37-48 AND 49-60 ARE BOTH 0.0 OR BLANK, THESE  -
CN              FIELDS WILL BE IGNORED.                                -
CN                                                                     -
CN              ROD POSITIONS AT THE ENDS OF EACH SUBINTERVAL DURING   -
CN              THE BURN CYCLE WILL BE DETERMINED BY LINEAR            -
CN              INTERPOLATION OF THE DATA SUPPLIED ON THESE CARDS.     -
CN                                                                     -
CN              IF TYPE 38 CARDS ARE NOT SUPPLIED FOR A CONTROL-ROD    -
CN              BANK WHICH IS SPECIFIED ON THE DATA SET A.NIP3 TYPE     -
CN              44 CARDS, THE CONTROL RODS IN THAT BANK WILL REMAIN AT -
CN              THE POSITIONS SPECIFIED ON THE A.NIP3 DATA THROUGHOUT   -
CN              THE COURSE OF THE PROBLEM.                             -
CN                                                                     -
CN              IF MORE THAN ONE AXIAL POSITION IS SPECIFIED FOR A     -
CN              PARTICULAR TIME, THE FIRST AXIAL POSITION ENCOUNTERED  -
CN              WILL BE USED FOR INTERPOLATION AT EARLIER SUBINTERVAL   -
CN              TIME POINTS, AND THE LAST ROD POSITION SPECIFIED FOR    -
CN              THAT PARTICULAR TIME WILL BE USED FOR LATER             -
CN              SUBINTERVAL TIME POINTS.                               -
CN                                                                     -
CN              THE ROD POSITION SPECIFIED FOR THE EARLIEST TIME ON    -
CN              ANY OF THE TYPE 38 CARDS FOR THE RODS IN A PARTICULAR  -
CN              CONTROL-ROD BANK WILL BE USED FOR THOSE RODS AT ANY    -
CN              EARLIER SUBINTERVAL TIME.  SUBINTERVAL TIMES WHICH ARE -
CN              LATER THAN THE LATEST TIME SPECIFIED ON ANY OF THE TYPE-
CN              38 CARDS FOR THE RODS IN THAT PARTICULAR CONTROL-ROD    -
CN              BANK WILL USE THE POSITION SPECIFIED FOR THAT LATEST    -
CN              TIME.                                                  -
```

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CN                                                                      -
CN              THE FIGURE BELOW ILLUSTRATES THE INTERPOLATION RULES    -
CN              DESCRIBED ABOVE.                                        -
CN                                                                      -
CN              Z3    |         |         |    *    X         X       -
CN                    |         |         |         |         |       -
CN              Z1    X    *    |         X         |         |       -
CN                    |         |         |         |         |       -
CN              Z22   |         X    +    |         |         |       -
CN                    |         |         |         |         |       -
CN              Z2    |         |    *    |         |         |       -
CN                                                                      -
CN                    T0  T(1)  T1  T(2)  T2  T(3)  T3        T4      -
CN                                                                      -
CN              THE VERTICAL LINES CORRESPOND TO THE SUBINTERVAL        -
CN              TIME BOUNDARIES, THE * AND + ARE INPUT VALUES SUPPLIED -
CN              ON THE TYPE 38 CARDS, AND THE X ARE THE RESULTING       -
CN              VALUES USED FOR THE ROD POSITIONS.  THE SUBINTERVAL     -
CN              TIME POINTS ARE T0, T1, T2, AND T3 AND THE INPUT DATA   -
CN              ARE SUPPLIED AT TIMES T(1), T(2), AND T(3).             -
CN              NOTE THAT ANY OF THE INPUT TIMES MIGHT HAVE COINCIDED   -
CN              WITH ONE OF THE SUBINTERVAL TIME POINTS.                -
CN              SINCE T0 FALLS BELOW THE EARLIEST INPUT VALUE AT        -
CN              T(1), THE ROD POSITION WILL BE DETERMINED BY THAT       -
CN              EARLIEST DATA POINT.  THE + DATA POINT IS ASSUMED TO    -
CN              HAVE BEEN SUPPLIED AFTER THE * POINT AND AT THE SAME    -
CN              TIME T(2) SO IT WILL BE USED FOR INTERPOLATIONS AT      -
CN              LATER TIMES.  THE VALUE USED AT TIME POINTS T3 AND T4   -
CN              ARE DETERMINED BY THE DATA POINT AT T(3).               -
CN              USING FREE FORMAT STYLE INPUT, THE INPUT FOR THE        -
CN              EXAMPLE ABOVE MIGHT HAVE BEEN GIVEN AS                  -
CN                                                                      -
CN                    38  BANK1  T(1) Z1  T(2) Z2                      -
CN                    38  BANK1  T(3) Z3  T(2) Z4                      -
CN                    38  BANK1  T(2) Z22                             -
CN                                                                      -
CN              NOTE THAT THREE POSITIONS HAVE BEEN SPECIFIED FOR TIME  -
CN              T(2).  THE LAST ONE ENCOUNTERED, Z22, IS USED FOR       -
CN              INTERPOLATIONS AT SUBINTERVAL TIME POINTS LATER THAN    -
CN              T(2) AND THE FIRST ONE SPECIFIED, Z2, IS USED FOR       -
CN              INTERPOLATIONS AT SUBINTERVAL TIME POINTS EARLIER THAN  -
CN              T(2).                                                   -
CN                                                                      -
CN              NOTE THAT IF THE INPUT DATA AT T(2) ABOVE HAD FALLEN    -
CN              AT T1, THE ROD POSITION AT T1 WOULD BE GIVEN BY THE *   -
CN              DATA POINT, AND THE + DATA POINT WOULD HAVE BEEN USED   -
CN              FOR DETERMINING THE POSITION AT T2.                     -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          BURNUP DEPENDENT GROUPS (TYPE 39)                           -
C                                                                       -
```

```
CL     FORMAT-----(I2,4X,3(A6,2I6))                                          -
C                                                                            -
CD   #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                     -
CD   =  =======  ========================================================-
CD   1   1-2     39                                                          -
CD                                                                           -
CD   2   7-12    LABEL OF BURNUP DEPENDENT ISOTOPE.                          -
CD                                                                           -
CD   3   13-18   BEGINNING NUMBER OF THE GROUP FOR WHICH THE CROSS          -
CD               SECTIONS ARE TO BE MODIFIED.                                -
CD                                                                           -
CD   4   19-24   ENDING NUMBER OF THE GROUP FOR WHICH THE CROSS             -
CD               SECTIONS ARE TO BE MODIFIED.                                -
CD                                                                           -
CD   5   25-30   LABEL OF BURNUP DEPENDENT ISOTOPE.                          -
CD                                                                           -
CD   6   31-36   BEGINNING NUMBER OF THE GROUP FOR WHICH THE CROSS          -
CD               SECTIONS ARE TO BE MODIFIED.                                -
CD                                                                           -
CD   7   37-42   ENDING NUMBER OF THE GROUP FOR WHICH THE CROSS             -
CD               SECTIONS ARE TO BE MODIFIED.                                -
CD                                                                           -
CD   8   43-48   LABEL OF BURNUP DEPENDENT ISOTOPE.                          -
CD                                                                           -
CD   9   49-54   BEGINNING NUMBER OF THE GROUP FOR WHICH THE CROSS          -
CD               SECTIONS ARE TO BE MODIFIED.                                -
CD                                                                           -
CD   10  55-60   ENDING NUMBER OF THE GROUP FOR WHICH THE CROSS             -
CD               SECTIONS ARE TO BE MODIFIED.                                -
C                                                                            -
CN               THE CROSS SECTIONS FOR THE ISOTOPES SPECIFIED IN COLS.      -
CN               7-12, 25-30, AND 43-48 WILL BE MODIFIED FOR THE GROUPS      -
CN               SPECIFIED IN COLS. 13-24, 31-42, AND 49-60.                 -
CN                                                                           -
CN               IF COLS. 19-24, 37-42, OR 55-60 ARE BLANK OR 0, THE         -
CN               CROSS SECTIONS WILL BE MODIFIED FOR THE GROUP SPECIFIED-
CN               IN COLS. 13-18, 31-36, OR 49-54, RESPECTIVELY.              -
CN                                                                           -
CN               IF COLS. 13-18, 31-36, OR 59-54 ARE 0 OR BLANK ON THE       -
CN               FIRST TYPE 39 CARD FOR A PARTICULAR BURNUP DEPENDENT        -
CN               ISOTOPE, THE CROSS SECTIONS FOR THAT ISOTOPE WILL BE        -
CN               MODIFIED FOR ALL GROUPS.                                    -
CN                                                                           -
CN               IF COLS. 7-12, 25-30, OR 43-48 ARE BLANK, THE REST OF       -
CN               THE DATA ON THAT CARD WILL BE IGNORED.                      -
CN                                                                           -
CN               THE TYPE 39 CARDS ARE NOT PERTINENT UNLESS TYPE 26          -
CN               CARDS HAVE BEEN SUPPLIED.                                   -
C                                                                            -
C-------------------------------------------------------------------------


C-------------------------------------------------------------------------
CR          POLYNOMIAL LEAST SQUARES CRITERIA (TYPE 40)                      -
```

```
C                                                                       -
CL    FORMAT-----(I2,4X,2(A6,I6,E12.5,I6)                               -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     40                                                      -
CD                                                                      -
CD  2   7-12    LABEL OF BURNUP DEPENDENT ISOTOPE.                      -
CD                                                                      -
CD  3   13-18   0...CAPTURE CROSS SECTIONS                              -
CD              1...FISSION CROSS SECTIONS                              -
CD              2...BOTH CAPTURE AND FISSION CROSS SECTIONS             -
CD                                                                      -
CD  4   19-30   ALLOWABLE ERROR IN THE ABSOLUTE VALUE OF THE RELATIVE  -
CD              RESIDUAL FOR ANY OF THE POINTS USED IN THE POLYNOMIAL  -
CD              FIT (DEFAULT=1.0E-3).                                  -
CD                                                                      -
CD  5   31-36   MAXIMUM ORDER FOR THE POLYNOMIAL FIT (DEFAULT=8).      -
CD                                                                      -
CD  6   37-42   LABEL OF BURNUP DEPENDENT ISOTOPE.                      -
CD                                                                      -
CD  7   43-48   0...CAPTURE CROSS SECTIONS                              -
CD              1...FISSION CROSS SECTIONS                              -
CD              2...BOTH CAPTURE AND FISSION CROSS SECTIONS             -
CD                                                                      -
CD  8   49-60   ALLOWABLE ERROR IN THE ABSOLUTE VALUE OF THE RELATIVE  -
CD              RESIDUAL FOR ANY OF THE POINTS USED IN THE POLYNOMIAL  -
CD              FIT (DEFAULT=1.0E-3).                                  -
CD                                                                      -
CD  9   61-66   MAXIMUM ORDER FOR THE POLYNOMIAL FIT (DEFAULT=8).      -
C                                                                       -
CN              THE CROSS SECTIONS WILL BE ASSUMED TO VARY ACCORDING    -
CN              TO A POLYNOMIAL EXPANSION OF THE ATOMIC DENSITY         -
CN              OF THE REFERENCE BASE ISOTOPE SO THAT                   -
CN                                                                      -
CN                  F = A0 + A1*C + A2*(C**2) +...+ AN*(C**N)           -
CN                                                                      -
CN              WHERE C IS THE ATOMIC DENSITY AND N IS THE ORDER        -
CN              OF THE FIT.  THE MULTIPLICATIVE FACTOR F WILL BE        -
CN              OBTAINED SEPARATELY FOR THE CROSS SECTION TYPES         -
CN              SPECIFIED IN COLS. 13-18 AND 43-48.                     -
CN                                                                      -
CN              IF COLS. 31-36 OR 61-66 ARE NEGATIVE, THE CROSS         -
CN              SECTIONS FOR THE CORRESPONDING ISOTOPE WILL BE          -
CN              ASSUMED TO VARY ACCORDING TO THE ABOVE POLYNOMIAL       -
CN              EXPRESSION BUT WHERE C IS THE NATURAL LOGARITHM OF      -
CN              THE ATOMIC DENSITY OF THE REFERENCE BASE ISOTOPE        -
CN              RATHER THAN JUST THE ATOMIC DENSITY ITSELF.             -
CN              THE LOGARITHMIC FITTING OPTION SHOULD BE USED WHEN      -
CN              ORDINARY LINEAR-LINEAR FITTING PRODUCES UNACCEPTABLE    -
CN              RESULTS.   TYPICALLY, THE LOGARITHMIC FITTING WILL      -
CN              BE APPROPRIATE THEN THE ATOMIC DENSITIES VARY OVER A    -
CN              NUMBER OF ORDERS OF MAGNITUDE.                          -
CN                                                                      -
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CN              THE RESIDUALS REFERRED TO IN COLS. 19-30 AND 49-60     -
CN              ARE OBTAINED AT EACH OF THE ATOM DENSITIES SPECIFIED ON-
CN              THE TYPE 41 CARDS.                                     -
CN                                                                     -
CN              IF COLS. 7-12 OR 37-42 ARE BLANK, THE REST OF THE DATA -
CN              ON THAT CARD WILL BE IGNORED.                          -
CN                                                                     -
CN              THE TYPE 40 CARDS ARE NOT PERTINENT UNLESS TYPE 26     -
CN              CARDS HAVE BEEN SUPPLIED.                              -
C                                                                      -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          BURNUP DEPENDENT FITTING DATA SPECIFICATIONS (TYPE 41)     -
C                                                                      -
CL    FORMAT-----(I2,4X,A6,2(A6,2E12.5))                               -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     41                                                     -
CD                                                                     -
CD  2   7-12    LABEL OF BURNUP DEPENDENT ISOTOPE.                     -
CD                                                                     -
CD  3   13-18   LABEL OF THE ISOTOPE WHOSE CROSS SECTIONS ARE TO BE    -
CD              INCLUDED IN THE POLYNOMIAL FITTING OF CROSS SECTION    -
CD              VS. THE ATOMIC DENSITY OF THE CORRESPONDING REFERENCE  -
CD              BASE ISOTOPE.                                          -
CD                                                                     -
CD  4   19-30   THE REFERENCE BASE ISOTOPE ATOMIC DENSITY               -
CD              CORRESPONDING TO THE CROSS SECTIONS OF THE ISOTOPE     -
CD              REFERENCED IN COLS. 13-18.                             -
CD                                                                     -
CD  5   31-42   WEIGHT FOR THE DATA AT THE ATOMIC DENSITY IN COLS.     -
CD              19-30 (DEFAULT=1.0).                                   -
CD                                                                     -
CD  6   43-48   LABEL OF THE ISOTOPE WHOSE CROSS SECTIONS ARE TO BE    -
CD              INCLUDED IN THE POLYNOMIAL FITTING OF CROSS SECTION    -
CD              VS. THE ATOMIC DENSITY OF THE CORRESPONDING REFERENCE  -
CD              BASE ISOTOPE.                                          -
CD                                                                     -
CD  7   49-60   THE REFERENCE BASE ISOTOPE ATOMIC DENSITY               -
CD              CORRESPONDING TO THE CROSS SECTIONS OF THE ISOTOPE     -
CD              REFERENCED IN COLS. 43-48.                             -
CD                                                                     -
CD  8   61-72   WEIGHT FOR THE DATA AT THE ATOMIC DENSITY IN COLS.     -
CD              49-60 (DEFAULT=1.0).                                   -
C                                                                      -
CN              COLS. 7-12 AND 13-18 MAY NOT BE BLANK.                 -
CN                                                                     -
CN              THESE DATA ARE USED TO OBTAIN THE COEFICIENTS OF A     -
CN              POLYNOMIAL EXPANSION (SEE CARD TYPE 40) USING A LEAST  -
CN              SQUARES FITTING PROCEDURE.  THE CODE WILL ADJUST THE   -
CN              ORDER OF THE POLYNOMIAL UNTIL THE ABSOLUTE VALUE OF THE-
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CN              RELATIVE RESIDUAL AT ANY OF THE DATA POINTS IS LESS    -
CN              THAN OR EQUAL TO THE ERROR SPECIFIED ON THE TYPE 40    -
CN              CARDS.  NOTE THAT THE ORDER OF THE FIT WILL IN GENERAL -
CN              VARY FROM GROUP TO GROUP AND BE DIFFERENT FOR CAPTURE  -
CN              AND FISSION.                                           -
CN                                                                     -
CN              THE ORDER OF THE POLYNOMIAL FIT SPECIFIED BY THE       -
CN              ABSOLUTE VALUE OF THE QUANTITY IN COLS. 31-36 OR       -
CN              OR 61-66 ON A TYPE 40 CARD FOR THE BURNUP DEPENDENT    -
CN              ISOTOPE IN COLS. 7-12 ON A TYPE 41 CARD MUST BE LESS   -
CN              THAN THE NUMBER OF ISOTOPES USED IN THE FITTING OF     -
CN              THAT BURNUP DEPENDENT ISOTOPE ON THE TYPE 41 CARDS.    -
CN              THUS IF 5 ISOTOPES ARE SPECIFIED ON THE TYPE 41 CARDS  -
CN              IN 13-18 AND 43-48, COLS. 31-36 OR 61-66 ON A TYPE 40  -
CN              CARD MUST BE 4 OR LESS FOR THE CORRESPONDING BURNUP    -
CN              DEPENDENT ISOTOPE.                                     -
CN                                                                     -
CN              NOTE THAT CONTRARY TO THE ISOTOPES SPECIFIED ON THE    -
CN              TYPE 26 CARDS, THE ISOTOPES USED FOR THE FITTING       -
CN              SPECIFIED IN COLS. 13-18 AND 43-48 ARE NORMALLY NOT    -
CN              INCLUDED IN THE REBUS-3 CALCULATION PER SE.  THUS, THE -
CN              LABELS IN COLS. 13-18 AND 43-48 NORMALLY WILL NOT      -
CN              APPEAR ON THE TYPE 09 OR 10 CARDS NOR ON THE TYPE 13   -
CN              AND/OR TYPE 14 CARDS OF DATA SET A.NIP3.               -
CN                                                                     -
CN              IF THE ATOMIC DENSITY DURING THE COURSE OF THE PROBLEM -
CN              FALLS OUTSIDE THE RANGE OF DENSITIES SPECIFIED ON THE  -
CN              TYPE 41 CARD FOR THE PARTICULAR REFERENCE BASE ISOTOPE,-
CN              THE PROBLEM WILL BE TERMINATED WITH A FATAL ERROR      -
CN              MESSAGE.                                               -
CN                                                                     -
CN              IF A WEIGHT OF 0.0 IS DESIRED, THAT VALUE MUST BE USED -
CN              EXPLICITLY IN COLS. 31-42 OR 61-72 SINCE A WEIGHT OF   -
CN              1.0 WILL BE USED IF THOSE COLUMNS ARE LEFT BLANK.      -
CN                                                                     -
CN              THE TYPE 41 CARDS ARE NOT PERTINENT UNLESS TYPE 26     -
CN              CARDS HAVE BEEN SUPPLIED.                              -
C                                                                      -
C----------------------------------------------------------------------


C----------------------------------------------------------------------
CR          NON-EQUILIBRIUM DISCHARGE RECOVERY FACTOR SPECIFICATIONS   -
CR          (TYPE 42)                                                  -
C                                                                      -
CL    FORMAT-----(I2,4X,A6,6X,3(A6,E12.5))                             -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATION, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     42                                                     -
CD                                                                     -
CD  2   7-12    DISCHARGE RECOVERY FACTOR SPECIFICATION LABEL (REPEATED-
CD              ON ADDITIONAL CARDS, IF NECESSARY).                    -
CD                                                                     -
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CD  3   19-24   ACTIVE ISOTOPE LABEL.                                      -
CD                                                                        -
CD  4   25-36   RECOVERY FACTOR (DEFAULT=0.0).                           -
CD                                                                        -
CD  5   37-42   ACTIVE ISOTOPE LABEL.                                     -
CD                                                                        -
CD  6   43-54   RECOVERY FACTOR (DEFAULT=0.0).                           -
CD                                                                        -
CD  7   55-60   ACTIVE ISOTOPE LABEL.                                     -
CD                                                                        -
CD  8   61-72   RECOVERY FACTOR (DEFAULT=0.0).                           -
C                                                                         -
CN              ALL ACTIVE ISOTOPE LABELS MUST BE DEFINED ON TYPE 09      -
CN              CARDS OR VIA THE PRESTORED BURNUP CHAINS.                 -
CN                                                                        -
CN              ANY ACTIVE ISOTOPE LABEL APPEARING ON A TYPE 42 CARD      -
CN              MUST ALSO BE SPECIFIED ON THE TYPE 18 AND TYPE 13         -
CN              CARDS.                                                    -
CN                                                                        -
CN              THE RECOVERY FACTORS WILL BE APPLIED TO THE AMOUNTS OF    -
CN              FUEL DISCHARGED FROM THE VARIOUS REGIONS SPECIFIED ON     -
CN              THE TYPE 43 CARDS BELOW FOR NON-EQUILIBRIUM PROBLEMS.     -
CN                                                                        -
CN              ANY ACTIVE ISOTOPE NOT SPECIFIED FOR A PARTICULAR         -
CN              DISCHARGE RECOVERY FACTOR SPECIFICATION LABEL WILL BE     -
CN              ASSIGNED A RECOVERY FACTOR OF 0.0.                        -
C                                                                         -
C-------------------------------------------------------------------------


C-------------------------------------------------------------------------
CR          NON-EQUILIBRIUM DISCHARGE REGIONS SPECIFICATIONS (TYPE 43)    -
C                                                                         -
CL    FORMAT-----(I2,4X,A6,10A6)                                          -
C                                                                         -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                   -
CD  =  =======  ========================================================-
CD  1   1-2     43                                                        -
CD                                                                        -
CD  2   7-12    DISCHARGE RECOVERY FACTOR SPECIFICATION LABEL (REPEATED-
CD              ON ADDITIONAL CARDS, IF NECESSARY).                       -
CD                                                                        -
CD  3   13-18   LABEL OF REGION OR AREA TO WHICH THE RECOVERY FACTORS     -
CD              ON THE TYPE 42 CARDS FOR THE LABEL IN COLS. 7-12 WILL     -
CD              BE APPLIED FOR DISCHARGED FUEL.                           -
CD                                                                        -
CD  4   19-24   LABEL OF REGION OR AREA TO WHICH THE RECOVERY FACTORS     -
CD              ON THE TYPE 42 CARDS FOR THE LABEL IN COLS. 7-12 WILL     -
CD              BE APPLIED FOR DISCHARGED FUEL.                           -
CD                                                                        -
CD  5   25-30   LABEL OF REGION OR AREA TO WHICH THE RECOVERY FACTORS     -
CD              ON THE TYPE 42 CARDS FOR THE LABEL IN COLS. 7-12 WILL     -
CD              BE APPLIED FOR DISCHARGED FUEL.                           -
CD                                                                        -
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CD  6   31-36   LABEL OF REGION OR AREA TO WHICH THE RECOVERY FACTORS  -
CD              ON THE TYPE 42 CARDS FOR THE LABEL IN COLS. 7-12 WILL  -
CD              BE APPLIED FOR DISCHARGED FUEL.                        -
CD                                                                     -
CD  7   37-42   LABEL OF REGION OR AREA TO WHICH THE RECOVERY FACTORS  -
CD              ON THE TYPE 42 CARDS FOR THE LABEL IN COLS. 7-12 WILL  -
CD              BE APPLIED FOR DISCHARGED FUEL.                        -
CD                                                                     -
CD  8   43-48   LABEL OF REGION OR AREA TO WHICH THE RECOVERY FACTORS  -
CD              ON THE TYPE 42 CARDS FOR THE LABEL IN COLS. 7-12 WILL  -
CD              BE APPLIED FOR DISCHARGED FUEL.                        -
CD                                                                     -
CD  9   49-54   LABEL OF REGION OR AREA TO WHICH THE RECOVERY FACTORS  -
CD              ON THE TYPE 42 CARDS FOR THE LABEL IN COLS. 7-12 WILL  -
CD              BE APPLIED FOR DISCHARGED FUEL.                        -
CD                                                                     -
CD 10   55-60   LABEL OF REGION OR AREA TO WHICH THE RECOVERY FACTORS  -
CD              ON THE TYPE 42 CARDS FOR THE LABEL IN COLS. 7-12 WILL  -
CD              BE APPLIED FOR DISCHARGED FUEL.                        -
CD                                                                     -
CD 11   61-66   LABEL OF REGION OR AREA TO WHICH THE RECOVERY FACTORS  -
CD              ON THE TYPE 42 CARDS FOR THE LABEL IN COLS. 7-12 WILL  -
CD              BE APPLIED FOR DISCHARGED FUEL.                        -
CD                                                                     -
CD 12   67-72   LABEL OF REGION OR AREA TO WHICH THE RECOVERY FACTORS  -
CD              ON THE TYPE 42 CARDS FOR THE LABEL IN COLS. 7-12 WILL  -
CD              BE APPLIED FOR DISCHARGED FUEL.                        -
C                                                                      -
CN              THE FUEL DISCHARGED FROM THE VARIOUS REGIONS SPECIFIED -
CN              ABOVE WILL BE COMBINED, AFTER APPLYING THE RECOVERY    -
CN              FACTORS SPECIFIED ON THE TYPE 42 CARDS TO FORM THE     -
CN              FEED COMPOSITIONS FOR THE VARIOUS FEEDS AS SPECIFIED   -
CN              ON THE TYPE 44 CARDS.                                  -
C                                                                      -
C----------------------------------------------------------------------


C----------------------------------------------------------------------
CR          NON-EQUILIBRIUM FEED MODIFICATION SPECIFICATIONS (TYPE 44) -
C                                                                      -
CL    FORMAT-----(I2,4X,A6,10A6)                                       -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     44                                                     -
CD                                                                     -
CD  2   7-12    EXTERNAL FEED LABEL (REPEATED ON ADDITIONAL CARDS, IF  -
CD              NECESSARY).                                            -
CD                                                                     -
CD  3   13-18   LABEL OF REGION OR AREA CONTRIBUTING TO THE COMPOSITION-
CD              OF THE EXTERNAL FEED SPECIFIED IN COLS. 7-12.          -
CD                                                                     -
CD  4   19-24   LABEL OF REGION OR AREA CONTRIBUTING TO THE COMPOSITION-
CD              OF THE EXTERNAL FEED SPECIFIED IN COLS. 7-12.          -
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CD                                                                      -
CD  5   25-30   LABEL OF REGION OR AREA CONTRIBUTING TO THE COMPOSITION-
CD              OF THE EXTERNAL FEED SPECIFIED IN COLS. 7-12.           -
CD                                                                      -
CD  6   31-36   LABEL OF REGION OR AREA CONTRIBUTING TO THE COMPOSITION-
CD              OF THE EXTERNAL FEED SPECIFIED IN COLS. 7-12.           -
CD                                                                      -
CD  7   37-42   LABEL OF REGION OR AREA CONTRIBUTING TO THE COMPOSITION-
CD              OF THE EXTERNAL FEED SPECIFIED IN COLS. 7-12.           -
CD                                                                      -
CD  8   43-48   LABEL OF REGION OR AREA CONTRIBUTING TO THE COMPOSITION-
CD              OF THE EXTERNAL FEED SPECIFIED IN COLS. 7-12.           -
CD                                                                      -
CD  9   49-54   LABEL OF REGION OR AREA CONTRIBUTING TO THE COMPOSITION-
CD              OF THE EXTERNAL FEED SPECIFIED IN COLS. 7-12.           -
CD                                                                      -
CD 10   55-60   LABEL OF REGION OR AREA CONTRIBUTING TO THE COMPOSITION-
CD              OF THE EXTERNAL FEED SPECIFIED IN COLS. 7-12.           -
CD                                                                      -
CD 11   61-66   LABEL OF REGION OR AREA CONTRIBUTING TO THE COMPOSITION-
CD              OF THE EXTERNAL FEED SPECIFIED IN COLS. 7-12.           -
CD                                                                      -
CD 12   67-72   LABEL OF REGION OR AREA CONTRIBUTING TO THE COMPOSITION-
CD              OF THE EXTERNAL FEED SPECIFIED IN COLS. 7-12.           -
C                                                                       -
CN              THE EXTERNAL FEED LABELS SPECIFIED IN COLS. 7-12 MUST   -
CN              CORRESPOND TO LABELS SPECIFIED ON THE TYPE 21 CARDS.    -
CN                                                                      -
CN              THE COMPOSITION OF THE EXTERNAL FEED SPECIFIED IN COLS.-
CN              7-12 WILL BE DETERMINED BY THE SUM OF ALL OF THE FUEL   -
CN              DISCHARGED FROM THE REGIONS SPECIFIED IN COLS. 13-72    -
CN              AFTER APPLYING THE RECOVERY FACTORS SPECIFIED ON THE    -
CN              TYPE 42 CARDS.                                          -
CN                                                                      -
CN              ANY EXTERNAL FEED NOT SPECIFIED ON A TYPE 44 CARD WILL  -
CN              RETAIN THE ISOTOPIC COMPOSITION PREVIOUSLY ASSIGNED     -
CN              EITHER VIA THE ORIGINAL INPUT DATA (SEE CARD TYPES      -
CN              21 AND 22) OR DUE TO DISCHARGE FROM PREVIOUSLY          -
CN              DISCHARGED FUEL.                                        -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          FUEL MANAGEMENT GROUP SPECIFICATIONS (TYPE 45)              -
C                                                                       -
CL    FORMAT-----(I2,4X,11A6)                                           -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  =======================================================-
CD  1   1-2     45                                                      -
CD                                                                      -
CD  2   7-12    FUEL MANAGEMENT GROUP LABEL.                            -
CD                                                                      -
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CD  3    13-18   REGION LABEL OR AREA LABEL FOR REGIONS CONTAINED IN    -
CD               THE FUEL MANAGEMENT GROUP DESIGNATED IN COLS. 7-12.    -
CD                                                                      -
CD  4    19-24   REGION LABEL OR AREA LABEL FOR REGIONS CONTAINED IN    -
CD               THE FUEL MANAGEMENT GROUP DESIGNATED IN COLS. 7-12.    -
CD                                                                      -
CD  5    25-30   REGION LABEL OR AREA LABEL FOR REGIONS CONTAINED IN    -
CD               THE FUEL MANAGEMENT GROUP DESIGNATED IN COLS. 7-12.    -
CD                                                                      -
CD  6    31-36   REGION LABEL OR AREA LABEL FOR REGIONS CONTAINED IN    -
CD               THE FUEL MANAGEMENT GROUP DESIGNATED IN COLS. 7-12.    -
CD                                                                      -
CD  7    37-42   REGION LABEL OR AREA LABEL FOR REGIONS CONTAINED IN    -
CD               THE FUEL MANAGEMENT GROUP DESIGNATED IN COLS. 7-12.    -
CD                                                                      -
CD  8    43-48   REGION LABEL OR AREA LABEL FOR REGIONS CONTAINED IN    -
CD               THE FUEL MANAGEMENT GROUP DESIGNATED IN COLS. 7-12.    -
CD                                                                      -
CD  9    49-54   REGION LABEL OR AREA LABEL FOR REGIONS CONTAINED IN    -
CD               THE FUEL MANAGEMENT GROUP DESIGNATED IN COLS. 7-12.    -
CD                                                                      -
CD  10   55-60   REGION LABEL OR AREA LABEL FOR REGIONS CONTAINED IN    -
CD               THE FUEL MANAGEMENT GROUP DESIGNATED IN COLS. 7-12.    -
CD                                                                      -
CD  11   61-66   REGION LABEL OR AREA LABEL FOR REGIONS CONTAINED IN    -
CD               THE FUEL MANAGEMENT GROUP DESIGNATED IN COLS. 7-12.    -
CD                                                                      -
CD  12   67-72   REGION LABEL OR AREA LABEL FOR REGIONS CONTAINED IN    -
CD               THE FUEL MANAGEMENT GROUP DESIGNATED IN COLS. 7-12.    -
C                                                                       -
CN               THE TYPE 45 CARDS PERMIT REDUCING THE NUMBER OF CARDS  -
CN               OF TYPE 11 OR 35 REQUIRED TO SPECIFY THE FUEL          -
CN               MANAGEMENT PATHS.  THIS IS PARTICULARY TRUE FOR 3D     -
CN               PROBLEMS WHERE TYPICALLY  ALL OF THE AXIAL REGIONS     -
CN               IN A FUEL ASSEMBLY WOULD BE TREATED TOGETHER AS FAR AS -
CN               THE FUEL MANAGEMENT IS CONCERNED.                      -
CN                                                                      -
CN               TYPE 45 CARDS INDICATE THE REGIONS WHICH WILL BE       -
CN               TREATED COLLECTIVELY DURING FUEL MANAGEMENT PATHS AS   -
CN               AS SPECIFIED ON THE TYPE 11 OR TYPE 35 CARDS.  IF A    -
CN               FUEL MANAGEMENT GROUP LABEL IS SPECIFIED ON A TYPE 11  -
CN               OR 35 CARD, ALL OF THE ASSOCIATED REGIONS WILL BE      -
CN               ASSIGNED THE CORRESPONDING FUEL MATERIAL FOR THE       -
CN               INDICATED STAGE OF THE PATH INVOLVED.                  -
CN                                                                      -
CN               COLS. 7-12 AND 13-18 MAY NOT BE BLANK.                 -
CN                                                                      -
CN               THE REGIONS CORRESPONDING TO A GIVEN FUEL MANAGEMENT   -
CN               GROUP MUST BE UNIQUE.  THAT IS, REGION LABELS MAY NOT  -
CN               BE REPEATED IN COLS 13-72 FOR A GIVEN FUEL MANAGEMENT  -
CN               GROUP AND THE REGIONS IMPLIED BY AREA LABELS MAY NOT BE-
CN               REPEATED FOR A GIVEN FUEL MANAGEMENT GROUP.            -
CN                                                                      -
CN               IF A BLANK FIELD IS ENCOUNTERED IN COLS. 13-18,        -
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CN              19-24, 25-30, 31-36, 37-42, 43-48, 49-54, 55-60,       -
CN              61-66, OR 67-72, THE REST OF THE DATA ON THAT TYPE 45  -
CN              CARD WILL BE IGNORED.                                  -
C                                                                      -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CD          USER DEFINED CONVERSION RATIO NUCLIDES (TYPE 46)           -
C                                                                      -
CL    FORMAT-----(I2,4X,5(A6,I6))                                      -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     46                                                     -
CD                                                                     -
CD  2   7-12    ACTIVE ISOTOPE LABEL.                                  -
CD                                                                     -
CD  3   13-18   CONVERSION RATIO ISOTOPE SET.                          -
CD                                                                     -
CD  4   19-24   ACTIVE ISOTOPE LABEL.                                  -
CD                                                                     -
CD  5   25-30   CONVERSION RATIO ISOTOPE SET.                          -
CD                                                                     -
CD  6   31-36   ACTIVE ISOTOPE LABEL.                                  -
CD                                                                     -
CD  7   37-42   CONVERSION RATIO ISOTOPE SET.                          -
CD                                                                     -
CD  8   43-48   ACTIVE ISOTOPE LABEL.                                  -
CD                                                                     -
CD  9   49-54   CONVERSION RATIO ISOTOPE SET.                          -
CD                                                                     -
CD 10   55-60   ACTIVE ISOTOPE LABEL.                                  -
CD                                                                     -
CD 11   61-66   CONVERSION RATIO ISOTOPE SET.                          -
CD                                                                     -
C                                                                      -
CN              ACTIVE ISOTOPE LABELS MUST BE DEFINED ON TYPE 09       -
CN              CARDS OR VIA A PRESTORED BURNUP CHAIN.                 -
CN                                                                     -
CN              THE TYPE 46 CARDS ARE USED TO SPECIFY THE NUCLIDES     -
CN              WHICH ARE INCLUDED IN THE CALCULATION OF THE USER      -
CN              DEFINED CONVERSION RATIO.                              -
CN                                                                     -
CN              COLS. 13-18, 25-30, 37-42, 49-54, and 61-66 MAY HAVE   -
CN              VALUES 1, 2, or 3 CORRESPONDING TO ISOTOPE SET 1,      -
CN              ISOTOPE SET 2, OR BOTH SET 1 AND SET 2.  IF ANY OF     -
CN              THESE IS LEFT BLANK, THE CORRESPONDING ISOTOPE WILL BE -
CN              ASSIGNED TO SET 1.  CONVERSION RATIOS WILL BE          -
CN              CALCULATED FOR THE ISOTOPES SPECIFIED IN SET 1 AND IF  -
CN              SPECIFIED, ALSO FOR SET 2.                             -
CN                                                                     -
CN              THE TYPE 46 CARDS PERMIT CALCULATION OF THE CONVERSION -
CN              RATIOS FOR TRANSURANIC AND/OR MINOR ACTINIDE ISOTOPES  -
```

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CN              IN ADDITION TO THE CONVERSION RATIO OF FISSILE          -
CN              ISOTOPES WHICH ARE DEFINED ON THE TYPE 24 CARDS.        -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CD          VARIABLE TIME STEP SPECIFICATION (TYPE 47)                  -
C                                                                       -
CL    FORMAT-----(I2,10X,5E12.5)                                        -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     47                                                      -
CD                                                                      -
CD  2   13-24   RELATIVE LENGTH OF 1ST SUBINTERVAL                      -
CD                                                                      -
CD  3   25-36   RELATIVE LENGTH OF 2ND SUBINTERVAL                      -
CD                                                                      -
CD  4   37-48   RELATIVE LENGTH OF 3RD SUBINTERVAL                      -
CD                                                                      -
CD  5   49-60   RELATIVE LENGTH OF 4TH SUBINTERVAL                      -
CD                                                                      -
CD  6   61-72   RELATIVE LENGTH OF 5TH SUBINTERVAL                      -
CD                                                                      -
C                                                                       -
CN              TYPE 47 CARDS ARE USED TO SPECIFIED THE SUBINTERVAL     -
CN              LENGTHS FOR DEPLETION CALCULATIONS. IF NO TYPE 47 CARD  -
CN              IS PROVIDED, THE CYCLE LENGTH IS DIVIDED INTO UNIFROM   -
CN              SUBINTERVALS.                                           -
CN                                                                      -
CN              THE NUMBER OF SUBINTERVALS SPECIFIED ON TYPE 47 CARDS   -
CN              SHOULD BE EQUAL TO THE NUMBER GIVEN IN COLUMNS 61-66    -
CN              OF TYPE 03 CARD. IF THE NUMBER OF SUBINTERVALS IS       -
CN              LARGER THAN 5, THE DATA BEYOND THE 5TH SUBINTERVAL      -
CN              SHOULD BE PROVIDED SEQUENTIALLY ON ADDITIONAL TYPE 47   -
CN              CARDS.                                                  -
CN                                                                      -
CN              THE SUBINTERVAL LENGTH SHOULD BE GIVEN AS A FRACTION    -
CN              OF THE CYCLE LENGTH.                                    -
C                                                                       -
C-----------------------------------------------------------------------

CEOF
```

Appendix C. Description of BCD Input Dataset A.NIP3

```
C*****************************************************************-
C                                                                 -
C                       PREPARED 8/28/75 AT ANL                   -
C                       LAST REVISED 5/1/92                       -
C                                                                 -
CF          A.NIP3                                                -
CE          NEUTRONICS MODEL INPUT FOR CODES WHICH REQUIRE CCCC    -
CE          INTERFACE FILES                                       -
C                                                                 -
CN                      THIS BCD DATA SET MAY BE WRITTEN EITHER   -
CN                      IN FREE FORMAT (UNFORM=A.NIP3) OR ACCORDING TO -
CN                      THE FORMATS SPECIFIED FOR EACH CARD TYPE  -
CN                      (DATASET=A.NIP3).                         -
CN                                                                -
CN                      COLUMNS 1-2 MUST CONTAIN THE CARD TYPE    -
CN                      NUMBER.                                   -
CN                                                                -
CN                      UNLESS OTHERWISE STATED, BLANKS ARE NOT   -
CN                      MEANINGFUL IN A6 LABEL FIELDS.            -
C                                                                 -
C                                                                 -
CN                ***  CARD TYPE DIRECTORY  ***                   -
CN                                                                -
CN    TYPE                    CONTENTS                            -
CN    ====    ==================================================  -
CN     01     PROBLEM TITLE                                       -
CN     02     INPUT PROCESSING SPECIFICATIONS                     -
CN     03     PROBLEM GEOMETRY                                    -
CN     04     EXTERNAL BOUNDARY CONDITIONS                        -
CN     05     EXTERNAL BOUNDARY CONDITION CONSTANTS               -
CN     06     REGION BOUNDARIES FOR ORTHOGONAL GEOMETRIES         -
CN     07     AREA SPECIFICATIONS                                 -
CN     09     VARIABLE-MESH STRUCTURE                             -
CN     10     INTERNAL BLACK ABSORBER CONDITIONS                  -
CN     11     INTERNAL BLACK ABSORBER CONDITION CONSTANTS         -
CN     12     FINITE-GEOMETRY TRANSVERSE DISTANCES                -
CN     13     MATERIAL SPECIFICATIONS                             -
CN     14     COMPOSITION (ZONE) SPECIFICATIONS                   -
CN     15     REGION/COMPOSITION CORRESPONDENCE                   -
CN     19     REGION OR MESH DISTRIBUTED INHOMOGENEOUS SOURCE     -
CN     21     SEARCH EDIT OPTIONS AND CONVERGENCE CRITERIA         -
CN     22     SEARCH PARAMETER DATA                               -
CN     23     CONCENTRATION MODIFIERS FOR CRITICALITY SEARCH      -
CN     24     MESH MODIFIERS FOR CRITICALITY SEARCH               -
CN     25     BUCKLING MODIFIERS FOR CRITICALITY SEARCH           -
CN     26     ALPHA MODIFIERS FOR CRITICALITY SEARCH              -
CN     29     HEXAGON DIMENSION                                   -
CN     30     REGION DEFINITIONS FOR ARRAYS OF HEXAGONS           -
CN     31     BACKGROUND REGION FOR ARRAYS OF HEXAGONS            -
CN     34     COMPOSITION- AND GROUP-DEPENDENT BUCKLINGS          -
CN     35     DIRECTIONAL DIFFUSION COEF. SCHEME                  -
CN     36     DIRECTIONAL DIFFUSION COEF./COMPOSITION CORRESPONDENCE -
CN     37     FISSION ENERGY CONVERSION FACTORS                   -
CN     38     CAPTURE ENERGY CONVERSION FACTORS                   -
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CN     39     NUCLIDE SET ASSIGNMENTS                                  -
CN     40     SOURCE EDIT, SYNTHESIS TRIAL FUNCTION SOURCE             -
CN     41     NATURAL DECAY INHOMOGENEOUS SOURCE                       -
CN     42     SOURCE SPECTRA                                           -
CN     43     GRAPHICS OUTPUT CONTROL                                  -
CN     44     ASSIGNMENT OF REGION TO CONTROL ROD BANK                 -
C                                                                      -
C**********************************************************************-


C----------------------------------------------------------------------
CR          PROBLEM TITLE (TYPE 01)                                    -
C                                                                      -
CL    FORMAT-----(I2,4X,11A6)                                          -
C                                                                      -
CD     COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD     =======  ========================================================-
CD      1-2     01                                                     -
CD                                                                     -
CD      7-72    ANY ALPHANUMERIC CHARACTERS.                           -
C                                                                      -
CN              ANY NUMBER OF TYPE 01 CARDS MAY BE USED.               -
C                                                                      -
C----------------------------------------------------------------------


C----------------------------------------------------------------------
CR          INPUT PROCESSING SPECIFICATION (TYPE 02)                   -
C                                                                      -
CL    FORMAT-----(I2,10X,8I6)                                          -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     02                                                     -
CD                                                                     -
CD  2   13-18   POINTR DEBUGGING EDIT FOR GEOMETRY PROCESSING MODULE.  -
CD              0...NO DEBUGGING PRINTOUT (DEFAULT).                   -
CD              1...DEBUGGING DUMP PRINTOUT.                           -
CD              2...DEBUGGING TRACE PRINTOUT.                          -
CD              3...FULL DEBUGGING PRINTOUT (DUMP+TRACE).              -
CD                                                                     -
CD  3   19-24   GEOMETRY PROCESSING MODULE EDIT.                       -
CD              0...NO EDITS (DEFAULT).                                -
CD              1...PRINT GEOMETRY EDITS.                              -
CD              2...WRITE GEOMETRY EDITS TO AUXILIARY OUTPUT FILE.     -
CD              3...GEOMETRY EDITS GO TO BOTH PRINT AND AUXILIARY      -
CD                  OUTPUT FILES.                                      -
CD                                                                     -
CD              OPTIONS 2 AND 3 ARE OPERATIVE ONLY FOR THOSE CODES     -
CD              WHICH RECOGNIZE AUXILIARY OUTPUT FILES.                -
CD                                                                     -
CD  4   25-30   SIZE OF MAIN CORE STORAGE ARRAY FOR GEOMETRY           -
CD              PROCESSING MODULE (GNIP4C) IN REAL*8 WORDS             -
CD              (DEFAULT=10000).                                       -
```

```
CD                                                                          -
CD  5    31-36   SIZE OF BULK CORE STORAGE ARRAY FOR GEOMETRY               -
CD               PROCESSING MODULE (GNIP4C) IN REAL*8 WORDS                 -
CD               (DEFAULT=0).                                               -
CD                                                                          -
CD  6    37-42   SIZE OF MAIN CORE STORAGE ARRAY FOR CROSS SECTION         -
CD               PROCESSING MODULES IN REAL*8 WORDS (DEFAULT = 20000).      -
CD                                                                          -
CD  7    43-48   SIZE OF BULK CORE STORAGE ARRAY FOR CROSS SECTION         -
CD               PROCESSING MODULES IN REAL*8 WORDS (DEFAULT=0).            -
CD                                                                          -
CD  8    49-54   POINTR DEBUGGING EDIT FOR CROSS SECTION PROCESSING        -
CD               MODULES.                                                   -
CD               0...NO DEBUGGING PRINTOUT (DEFAULT).                       -
CD               1...DEBUGGING DUMP PRINTOUT.                               -
CD               2...DEBUGGING TRACE PRINTOUT.                              -
CD               3...FULL DEBUGGING PRINTOUT (DUMP+TRACE).                  -
CD                                                                          -
CD  9    55-60   CROSS SECTION PROCESSING EDIT.                             -
CD               0...NO EDITS (DEFAULT).                                    -
CD               1...PRINT CROSS SECTION EDITS.                             -
CD               2...WRITE CROSS SECTION EDITS TO AUXILIARY OUTPUT FILE.-
CD               3...CROSS SECTION EDITS GO TO BOTH PRINT AND AUXILIARY -
CD                   OUTPUT FILES.                                          -
CD                                                                          -
CD  10   61-66   REGION/MESH INTERVAL PRINTER-PLOTTER MAP EDIT DURING      -
CD               GEOMETRY PROCESSING.                                       -
CD               0...NO MAP (DEFAULT).                                      -
CD               1...PRINT REGION MAP.                                      -
CD               2...WRITE REGION MAP TO AUXILIARY OUTPUT FILE.             -
CD               3...WRITE REGION MAP TO BOTH PRINT AND AUXILIARY OUTPUT-
CD                   FILES.                                                 -
CD                                                                          -
CD  11   67-72   ZONE(COMPOSITION)/MESH INTERVAL PRINTER-PLOTTER MAP       -
CD               EDIT DURING GEOMETRY PROCESSING.                           -
CD               0...NO MAP (DEFAULT).                                      -
CD               1...PRINT ZONE MAP.                                        -
CD               2...WRITE ZONE MAP TO AUXILIARY OUTPUT FILE.               -
CD               3...WRITE ZONE MAP TO BOTH PRINT AND AUXILIARY OUTPUT      -
CD                   FILES.                                                 -
CD                                                                          -
CN               EDIT OPTIONS 2 AND 3 ARE OPERATIVE ONLY FOR THOSE          -
CN               CODES WHICH RECOGNIZE AUXILIARY OUTPUT FILES.              -
CN                                                                          -
CN               THE PRINTER-PLOTTER MAP OPTIONS (COLS. 61-72) ARE          -
CN               ENTIRELY SEPARATE FROM THE GRAPHICS MAP OPTIONS            -
CN               IN COLS. 7-48 OF THE TYPE 43 CARD.                         -
C                                                                           -
C---------------------------------------------------------------------------


C---------------------------------------------------------------------------
CR          PROBLEM GEOMETRY SPECIFICATION (TYPE 03)                        -
C                                                                           -
```

```
CL    FORMAT-----(I2,10X,I6)                                                -
C                                                                           -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY.                    -
CD  =  =======  ========================================================-
CD  1   1-2     03                                                        -
CD                                                                        -
CD  2   13-18   GEOMETRY TYPE.                                            -
CD              10...SLAB                                                 -
CD              20...CYLINDER                                             -
CD              30...SPHERE                                               -
CD              40...X-Y                                                  -
CD              44...X-Y-Z                                                -
CD              50...R-Z                                                  -
CD              60...R-THETA                                              -
CD              62...R-THETA-Z                                            -
CD              64...THETA-R                                              -
CD              66...THETA-R-Z                                            -
CD              70...TRIANGULAR, RHOMBIC BOUNDARY, CORE CENTER AT         -
CD                   60 DEGREE ANGLE (SIXTH CORE SYMMETRY).               -
CD              72...TRIANGULAR, RECTANGULAR BOUNDARY, HALF CORE          -
CD                   SYMMETRY.                                            -
CD              74...TRIANGULAR, RHOMBIC BOUNDARY, CORE CENTER AT         -
CD                   120 DEGREE ANGLE (THIRD CORE SYMMETRY).              -
CD              76...TRIANGULAR, 60 DEGREE TRIANGULAR BOUNDARY,           -
CD                   SIXTH CORE SYMMETRY.                                 -
CD              78...TRIANGULAR, RECTANGULAR BOUNDARY, QUARTER            -
CD                   CORE SYMMETRY.                                       -
CD              80...TRIANGULAR, RECTANGULAR BOUNDARY, FULL CORE.         -
CD              90...TRIANGULAR-Z, RHOMBIC BOUNDARY IN PLANE, CORE        -
CD                   CENTER LINE AT 60 DEGREE ANGLE.                      -
CD              92...TRIANGULAR-Z, RECTANGULAR BOUNDARY IN PLANE,         -
CD                   HALF CORE SYMMETRY IN PLANE.                         -
CD              94...TRIANGULAR-Z, RHOMBIC BOUNDARY IN PLANE, CORE        -
CD                   CENTER LINE AT 120 DEGREE ANGLE.                     -
CD              96...TRIANGULAR-Z, 60 DEGREE TRIANGULAR BOUNDARY          -
CD                   IN PLANE.                                            -
CD              98...TRIANGULAR-Z, RECTANGULAR BOUNDARY IN PLANE,         -
CD                   QUARTER CORE SYMMETRY IN PLANE.                      -
CD             100...TRIANGULAR-Z, RECTANGULAR BOUNDARY IN PLANE,         -
CD                   FULL CORE IN PLANE.                                  -
CD             110...HEXAGONAL, FULL CORE.                                -
CD             114...HEXAGONAL, SIXTH CORE SYMMETRY.                      -
CD             116...HEXAGONAL, THIRD CORE SYMMETRY.                      -
CD             120...HEXAGONAL-Z, FULL CORE IN PLANE.                     -
CD             124...HEXAGONAL-Z, SIXTH CORE SYMMETRY IN PLANE.           -
CD             126...HEXAGONAL-Z, THIRD CORE SYMMETRY IN PLANE.           -
CD                                                                        -
C                                                                         -
C                                                                         -
C-------------------------------------------------------------------------


C-------------------------------------------------------------------------
CR          EXTERNAL BOUNDARY CONDITIONS (TYPE 04)                        -
```

```
C                                                                       -
CL    FORMAT-----(I2,10X,616)                                           -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     04                                                      -
CD                                                                      -
CD  2   13-18   BOUNDARY CONDITION AT LOWER "X" BOUNDARY OF REACTOR.    -
CD                                                                      -
CD  3   19-24   BOUNDARY CONDITION AT UPPER "X" BOUNDARY OF REACTOR.    -
CD                                                                      -
CD  4   25-30   BOUNDARY CONDITION AT LOWER "Y" BOUNDARY OF REACTOR.    -
CD                                                                      -
CD  5   31-36   BOUNDARY CONDITION AT UPPER "Y" BOUNDARY OF REACTOR.    -
CD                                                                      -
CD  6   37-42   BOUNDARY CONDITION AT LOWER Z BOUNDARY OF REACTOR.      -
CD                                                                      -
CD  7   43-48   BOUNDARY CONDITION AT UPPER Z BOUNDARY OF REACTOR.      -
CD                                                                      -
CD                                                                      -
CD              2...PHI=0.                                              -
CD              3...PHI PRIME=0.                                        -
CD              4...D * PHI PRIME + A * PHI = 0.                        -
CD              6...REPEATING (PERIODIC) WITH OPPOSITE FACE.            -
CD              7...REPEATING (PERIODIC) WITH NEXT ADJACENT BOUNDARY    -
CD                  (SEE DISCUSSION BELOW).                             -
CD              8...INVERTED REPEATING ALONG THIS FACE                  -
CD                  (180 DEGREE ROTATION).                              -
CD              9...INCOMING ANGULAR FLUX ZERO (TRANSPORT ONLY).        -
CD              10..REFLECTIVE (TRANSPORT ONLY).                        -
CD              11..PERIODIC (TRANSPORT ONLY).                          -
CD              12..WHITE (TRANSPORT ONLY).                             -
CD                                                                      -
C                                                                       -
CN              PHI PRIME IS THE DERIVATIVE OF THE FLUX IN THE          -
CN              DIRECTION OF THE REACTOR OUTWARD NORMAL. D IS THE       -
CN              DIFFUSION COEFFICIENT IN THE MESH INTERVAL              -
CN              IMMEDIATELY INSIDE THE REACTOR BOUNDARY. IF COLS.       -
CN              43-48 ARE 4 AND NO TYPE 05 CARD IS SUPPLIED TO SPECIFY -
CN              THE CONSTANT A, THE VALUE 0.46920 WILL BE USED BY       -
CN              DEFAULT.                                                -
CN                                                                      -
CN              CONDITIONS 2-8 APPLY TO DIFFUSION THEORY PROBLEMS,      -
CN              AND 9-12 APPLY TO TRANSPORT THEORY PROBLEMS.            -
CN                                                                      -
CN              "X" REPRESENTS THE FIRST DIMENSION COORDINATE (X IN     -
CN              X-Y GEOMETRY, R IN R-Z, ETC.). "Y" REPRESENTS THE       -
CN              SECOND DIMENSION COORDINATE (Y IN X-Y GEOMETRY, Z IN    -
CN              R-Z, ETC.). WHEN THE MODEL IS THREE-DIMENSIONAL, THE    -
CN              THIRD DIMENSION IS ALWAYS Z.                            -
CN                                                                      -
CN              REPEATING CONDITIONS (6,7,8) ARE ONLY APPLICABLE TO     -
CN              THE FIRST TWO DIMENSIONS.                               -
CN                                                                      -
```

```
CN              NOTE FOR REPEATING CONDITION 7.  LET XL DENOTE THE     -
CN              LOWER "X" BOUNDARY, XU DENOTE THE UPPER "X" BOUNDARY,  -
CN              YL DENOTE THE LOWER "Y" BOUNDARY AND YU DENOTE THE     -
CN              UPPER Y BOUNDARY.  FOR REPEATING BOUNDARY CONDITIONS   -
CN              (CONDITION 7), THE SEQUENCE OF BOUNDARIES IMPLIED BY   -
CN              THE TERM "NEXT ADJACENT BOUNDARY" IS XL, YL, XU, YU.   -
CN              OF THE TWO BOUNDARIES INVOLVED, THE ONE APPEARING      -
CN              FIRST IN THE SEQUENCE IS ASSIGNED THE BOUNDARY         -
CN              CONDITION (7), THE SECOND IS IGNORED.  FOR EXAMPLE,    -
CN              IF XL AND YL ARE THE PERIODIC BOUNDARIES, COLS. 13-18  -
CN              MUST CONTAIN A 7, COLS. 25-30 WILL BE IGNORED.         -
C                                                                      -
C               DIF3D-Nodal hex boundary condition examples            -
C               110: 04 4 4 4 4                                        -
C               114: 04 7 4 4 4                                        -
C               116: 04 7 4 0 4                                        -
C               120: 04 4 4 4 4  4 4                                   -
C               124: 04 7 4 4 4  4 4                                   -
C               126: 04 7 4 0 4  4 4                                   -
C                                                                      -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          EXTERNAL BOUNDARY CONDITION CONSTANTS (TYPE 05)             -
C                                                                       -
CL    FORMAT-----(I2,8X,A2,E12.5,12X,2I6)                               -
C                                                                       -
CD  #  COLUMNS    CONTENTS...IMPLICATIONS, IF ANY                       -
CD  =  =======  ============================================================-
CD  1   1-2     05                                                      -
CD                                                                      -
CD  2   11-12   BOUNDARY DESIGNATOR.                                   -
CD              XL..."X" LOWER.                                         -
CD              XU..."X" UPPER.                                         -
CD              YL..."Y" LOWER.                                         -
CD              YU..."Y" UPPER.                                         -
CD              ZL...Z LOWER.                                           -
CD              ZU...Z UPPER.                                           -
CD                                                                      -
CD  3   13-24   VALUE OF CONSTANT A REFERRED TO ON CARD TYPE 04.        -
CD                                                                      -
CD  4   37-42   HIGHER-ENERGY GROUP NUMBER FOR WHICH CONSTANTS APPLY.   -
CD                                                                      -
CD  5   43-48   LOWER-ENERGY GROUP NUMBER FOR WHICH CONSTANTS APPLY.    -
C                                                                       -
CN              AS MANY TYPE 05 CARDS AS NECESSARY MAY BE USED TO       -
CN              SPECIFY THE EXTERNAL BOUNDARY CONDITIONS.               -
CN                                                                      -
CN              IF NO "HIGHER-ENERGY GROUP NUMBER" IS SUPPLIED (COLS.   -
CN              37-42 ARE BLANK), THE CONSTANTS GIVEN APPLY TO ALL      -
CN              ENERGY GROUPS. IF NO "LOWER-ENERGY GROUP NUMBER" IS     -
CN              SUPPLIED (COLS. 43-48 ARE BLANK), THE CONSTANTS GIVEN   -
CN              APPLY TO THE "HIGHER-ENERGY GROUP" ONLY. IF NO GROUP    -
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CN              NUMBERS ARE SUPPLIED (COLS. 37-48 ARE BLANK), THE      -
CN              CONSTANTS GIVEN APPLY TO ALL ENERGY GROUPS.            -
CN                                                                     -
CN              DATA ON THIS CARD MAY BE OVERLAYED. THAT IS, BOUNDARY  -
CN              CONSTANTS DEFINED ON LATER TYPE 5 CARDS SUPERSEDE DATA -
CN              FOR ENERGY RANGES PREVIOUSLY SPECIFIED.                -
CN                                                                     -
CN              "X" REPRESENTS THE FIRST DIMENSION COORDINATE (X IN    -
CN              X-Y GEOMETRY, R IN R-Z, ETC.). "Y" REPRESENTS THE      -
CN              SECOND DIMENSION COORDINATE (Y IN X-Y GEOMETRY, Z IN   -
CN              R-Z, ETC.). WHEN THE MODEL IS THREE-DIMENSIONAL, THE   -
CN              THIRD DIMENSION IS ALWAYS Z.                           -
C                                                                      -
C----------------------------------------------------------------------


C----------------------------------------------------------------------
CR          REGION BOUNDARY COORDINATES AND CONSTANT MESH STRUCTURE    -
CR          (TYPE 06)                                                  -
C                                                                      -
CL    FORMAT-----(I2,4X,A6,2E12.5,2I6,2E12.5)                          -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     06                                                     -
CD                                                                     -
CD  2   7-12    REGION LABEL (REPEATED ON ADDITIONAL TYPE 06 CARDS).    -
CD                                                                     -
CD  3   13-24   "X"-DIRECTION LOWER-BOUNDARY COORDINATE.               -
CD                                                                     -
CD  4   25-36   "X"-DIRECTION UPPER-BOUNDARY COORDINATE.               -
CD                                                                     -
CD  5   37-42   FOR ONE-DIMENSIONAL AND TWO-DIMENSIONAL GEOMETRIES,    -
CD              NUMBER OF INTERVALS IN "X"-DIRECTION.                  -
CD                                                                     -
CD                                    ** OR **                         -
CD                                                                     -
CD              FOR THREE-DIMENSIONAL GEOMETRIES, LOWER Z MESH         -
CD              LINE NUMBER OF THE REGION.                             -
CD                                                                     -
CD  6   43-48   FOR TWO-DIMENSIONAL GEOMETRIES, NUMBER OF INTERVALS    -
CD              IN "Y"-DIRECTION.                                      -
CD                                                                     -
CD                                    ** OR **                         -
CD                                                                     -
CD              FOR THREE-DIMENSIONAL GEOMETRIES, UPPER Z MESH         -
CD              LINE NUMBER OF THE REGION.                             -
CD                                                                     -
CD  7   49-60   "Y"-DIRECTION LOWER-BOUNDARY COORDINATE.               -
CD                                                                     -
CD  8   61-72   "Y"-DIRECTION UPPER-BOUNDARY COORDINATE.               -
C                                                                      -
CN              CARD TYPE 06 IS NOT PERTINENT FOR TRIANGULAR,          -
CN              TRIANGULAR-Z, HEXAGONAL, OR HEXAGONAL-Z GEOMETRIES.    -
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CN              SEE CARD TYPE 30.                                       -
CN                                                                      -
CN              "X" REPRESENTS THE FIRST DIMENSION COORDINATE (X IN     -
CN              X-Y GEOMETRY, R IN R-Z, ETC.). "Y" REPRESENTS THE       -
CN              SECOND DIMENSION COORDINATE (Y IN X-Y GEOMETRY, Z IN    -
CN              R-Z, ETC.). WHEN THE MODEL IS THREE-DIMENSIONAL, THE    -
CN              THIRD DIMENSION IS ALWAYS Z.                            -
C                                                                       -
CN              IN GEOMETRIES INVOLVING AN ANGULAR DIMENSION (THETA)    -
CN              THE ANGULAR VARIABLE MUST BE GIVEN IN RADIANS.          -
CN                                                                      -
CN              REGIONS MAY BE DEFINED USING THE OVERLAY PRECEDURE,     -
CN              WITH THE LATEST REGION ASSIGNMENT OVERLAYING THE        -
CN              PREVIOUS CONFIGURATION, OR USING THE USUAL PROCEDURE,   -
CN              WITH EACH REGION'S BOUNDARIES GIVEN EXPLICITLY.         -
CN              REGION LABELS MUST BE NON-BLANK.                        -
CN                                                                      -
CN              THE MESH FOR A DIRECTION MUST BE COMPLETELY SPECIFIED   -
CN              EITHER ON THE TYPE 06 OR 09 CARDS. IF MESH DATA ARE     -
CN              SUPPLIED ON BOTH TYPE 06 AND 09 CARDS, THE TYPE 09      -
CN              DATA WILL BE USED.                                      -
CN                                                                      -
CN              FOR ONE-DIMENSIONAL PROBLEMS, ONLY THE "X"-DIRECTION    -
CN              UPPER BOUNDARIES NEED BE GIVEN FOR REGIONS AFTER THE    -
CN              FIRST.  IF THIS OPTION IS USED THE TYPE 6 CARDS MUST    -
CN              BE ARRANGED SO AS TO DEFINE REGIONS SEQUENTIALLY,       -
CN              MOVING FROM LEFT TO RIGHT.  IN OTHER WORDS THE          -
CN              X-DIRECTION UPPER BOUNDARIES MUST BE IN ASCENDING       -
CN              ORDER.                                                  -
CN                                                                      -
CN              FOR THREE-DIMENSIONAL GEOMETRIES, THE DEFINITION OF     -
CN              THE MESH STRUCTURE MUST BE SUPPLIED ON TYPE 09 CARDS.   -
CN                                                                      -
CN              THE LOWEST Z MESH LINE NUMBER (CORRESPONDING TO THE     -
CN              FIRST Z BOUNDARY) OF THE MODEL IS 0 (ZERO). THE         -
CN              LARGEST Z MESH LINE NUMBER (CORRESPONDING TO THE        -
CN              SECOND Z BOUNDARY) IS EQUAL TO THE NUMBER OF Z MESH     -
CN              INTERVALS.                                              -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          AREA SPECIFICATIONS (TYPE 07)                               -
C                                                                       -
CL    FORMAT-----(I2,4X,11A6)                                           -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     07                                                      -
CD                                                                      -
CD  2   7-12    AREA LABEL (REPEATED ON ADDITIONAL TYPE 07 CARDS).       -
CD                                                                      -
CD  3   13-18   LABEL OF REGION COMPRISING AREA.                        -
```

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CD                                                                              -
CD  4   19-24   LABEL OF REGION COMPRISING AREA.                                 -
CD                                                                              -
CD  5   25-30   LABEL OF REGION COMPRISING AREA.                                 -
CD                                                                              -
CD  6   31-36   LABEL OF REGION COMPRISING AREA.                                 -
CD                                                                              -
CD  7   37-42   LABEL OF REGION COMPRISING AREA.                                 -
CD                                                                              -
CD  8   43-48   LABEL OF REGION COMPRISING AREA.                                 -
CD                                                                              -
CD  9   49-54   LABEL OF REGION COMPRISING AREA.                                 -
CD                                                                              -
CD  10  55-60   LABEL OF REGION COMPRISING AREA.                                 -
CD                                                                              -
CD  11  61-66   LABEL OF REGION COMPRISING AREA.                                 -
CD                                                                              -
CD  12  67-72   LABEL OF REGION COMPRISING AREA.                                 -
C                                                                               -
CN              AREA LABELS MUST BE NON-BLANK. THE FIRST BLANK REGION           -
CN              LABEL ENCOUNTERED TERMINATES READING OF THE DATA ON             -
CN              THAT PARTICULAR TYPE 07 CARD. A REGION CAN BE PLACED            -
CN              IN AS MANY AREAS AS THE USER DESIRES.                           -
CN                                                                              -
CN              THE CONCEPT OF AREAS DOES NOT EXIST IN THE CCCC                 -
CN              ENVIRONMENT. ONLY CERTAIN CODES WRITTEN AT ANL MAKE             -
CN              USE OF AREAS, AND IN THOSE CODES AREAS ARE USED FOR             -
CN              EDIT PURPOSES ONLY.                                             -
C                                                                               -
C--------------------------------------------------------------------------------


C--------------------------------------------------------------------------------
CR          VARIABLE-MESH STRUCTURE (TYPE 09)                                   -
C                                                                               -
CL    FORMAT-----(I2,9X,A1,3(I6,E12.5))                                         -
C                                                                               -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                         -
CD  =  =======  ========================================================-
CD  1   1-2     09                                                              -
CD                                                                              -
CD  2   12      COORDINATE DIRECTION.                                           -
CD              X..."X" COORDINATE DIRECTION.                                   -
CD              Y..."Y" COORDINATE DIRECTION.                                   -
CD              Z...Z-COORDINATE DIRECTION.                                     -
CD                                                                              -
CD  3   13-18   NUMBER OF INTERVALS.                                            -
CD                                                                              -
CD  4   19-30   UPPER COORDINATE.                                               -
CD                                                                              -
CD  5   31-36   NUMBER OF INTERVALS.                                            -
CD                                                                              -
CD  6   37-48   UPPER COORDINATE.                                               -
CD                                                                              -
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CD  7   49-54   NUMBER OF INTERVALS.                                      -
CD                                                                       -
CD  8   55-66   UPPER COORDINATE.                                        -
C                                                                        -
CN              NOTE THAT A Z IN COL. 12 IS PERTINENT ONLY IF THE        -
CN              GEOMETRY IS THREE-DIMENSIONAL.                           -
CN                                                                       -
CN              "X" REPRESENTS THE FIRST DIMENSION COORDINATE (X IN      -
CN              X-Y GEOMETRY, R IN R-Z, ETC.). "Y" REPRESENTS THE        -
CN              SECOND DIMENSION COORDINATE (Y IN X-Y GEOMETRY, Z IN     -
CN              R-Z, ETC.). WHEN THE MODEL IS THREE-DIMENSIONAL, THE     -
CN              THIRD DIMENSION IS ALWAYS Z.                             -
C                                                                        -
CN              IN GEOMETRIES INVOLVING AN ANGULAR DIMENSION (THETA)     -
CN              THE ANGULAR VARIABLE MUST BE GIVEN IN RADIANS.           -
CN                                                                       -
CN              EACH NUMBER PAIR IS OF THE FORM (N(I), X(I)). THERE      -
CN              ARE N(I) INTERVALS BETWEEN X(I-1) AND X(I), WHERE X(0)   -
CN              IS THE LOWER REACTOR BOUNDARY IN THIS DIRECTION.         -
CN              NUMBER PAIRS MUST BE GIVEN IN ORDER OF INCREASING        -
CN              MESH COORDINATES. ALL REGION BOUNDARIES MUST COINCIDE    -
CN              WITH THE MESH LINES THAT BOUND MESH INTERVALS.           -
C                                                                        -
C-------------------------------------------------------------------------


C-------------------------------------------------------------------------
CR          INTERNAL BLACK ABSORBER CONDITIONS (TYPE 10)                 -
C                                                                        -
CL    FORMAT-----(I2,10X,10A6)                                           -
C                                                                        -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                  -
CD  =  =======  ========================================================-
CD  1   1-2     10                                                       -
CD                                                                       -
CD  2   13-18   LABEL OF COMPOSITION (CCCC ZONE) WHICH IS TO BE          -
CD              TREATED WITH INTERNAL BLACK BOUNDARY CONDITION.          -
CD                                                                       -
CD  3   19-24   LABEL OF COMPOSITION (CCCC ZONE) WHICH IS TO BE          -
CD              TREATED WITH INTERNAL BLACK BOUNDARY CONDITION.          -
CD                                                                       -
CD  4   25-30   LABEL OF COMPOSITION (CCCC ZONE) WHICH IS TO BE          -
CD              TREATED WITH INTERNAL BLACK BOUNDARY CONDITION.          -
CD                                                                       -
CD  5   31-36   LABEL OF COMPOSITION (CCCC ZONE) WHICH IS TO BE          -
CD              TREATED WITH INTERNAL BLACK BOUNDARY CONDITION.          -
CD                                                                       -
CD  6   37-42   LABEL OF COMPOSITION (CCCC ZONE) WHICH IS TO BE          -
CD              TREATED WITH INTERNAL BLACK BOUNDARY CONDITION.          -
CD                                                                       -
CD  7   43-48   LABEL OF COMPOSITION (CCCC ZONE) WHICH IS TO BE          -
CD              TREATED WITH INTERNAL BLACK BOUNDARY CONDITION.          -
CD                                                                       -
CD  8   49-54   LABEL OF COMPOSITION (CCCC ZONE) WHICH IS TO BE          -
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CD              TREATED WITH INTERNAL BLACK BOUNDARY CONDITION.          -
CD                                                                       -
CD  9   55-60   LABEL OF COMPOSITION (CCCC ZONE) WHICH IS TO BE          -
CD              TREATED WITH INTERNAL BLACK BOUNDARY CONDITION.          -
CD                                                                       -
CD  10  61-66   LABEL OF COMPOSITION (CCCC ZONE) WHICH IS TO BE          -
CD              TREATED WITH INTERNAL BLACK BOUNDARY CONDITION.          -
CD                                                                       -
CD  11  67-72   LABEL OF COMPOSITION (CCCC ZONE) WHICH IS TO BE          -
CD              TREATED WITH INTERNAL BLACK BOUNDARY CONDITION.          -
C                                                                        -
CN              AS MANY TYPE 10 CARDS CAN BE USED AS ARE NECESSARY TO    -
CN              SPECIFY ALL OF THE DESIRED COMPOSITION (CCCC ZONE)       -
CN              LABELS.                                                  -
CN                                                                       -
CN              EACH REGION WHICH IS COMPOSED OF ANY COMPOSITION         -
CN              LISTED ON TYPE 10 CARDS WILL BE TREATED AS A BLACK       -
CN              ABSORBER ACCORDING TO THE INTERNAL BOUNDARY CONDITIONS   -
CN              GIVEN ON TYPE 11 CARDS TO FOLLOW.                        -
CN                                                                       -
CN              THE REGIONS WHICH ARE COMPRISED OF THESE COMPOSITIONS     -
CN              ARE SPECIFIED ON TYPE 15 CARDS.                          -
CN                                                                       -
CN              THE FIRST BLANK COMPOSITION LABEL TERMINATES READING     -
CN              OF THE DATA ON THAT PARTICULAR TYPE 10 CARD.              -
C                                                                        -
C-------------------------------------------------------------------------


C-------------------------------------------------------------------------
CR          INTERNAL BLACK ABSORBER CONDITION CONSTANTS                   -
CR          (TYPE 11)                                                    -
C                                                                        -
CL    FORMAT-----(I2,4X,A6,2E12.5,24X,2I6)
C                                                                        -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                  -
CD  =  =======  ========================================================-
CD  1   1-2     11                                                       -
CD                                                                       -
CD  2   7-12    LABEL OF COMPOSITION (CCCC ZONE) FOR WHICH CONSTANTS      -
CD              APPLY.                                                   -
CD                                                                       -
CD  3   13-24   THE CONSTANT A, DEFINED BELOW.                           -
CD                                                                       -
CD  4   25-36   THE CONSTANT B, DEFINED BELOW.                           -
CD                                                                       -
CD  5   61-66   HIGHER-ENERGY GROUP NUMBER FOR WHICH CONSTANTS APPLY.    -
CD                                                                       -
CD  6   67-72   LOWER-ENERGY GROUP NUMBER FOR WHICH CONSTANTS APPLY.     -
C                                                                        -
CN              THE INTERNAL BLACK BOUNDARY CONDITION IS SPECIFIED AS    -
CN                                                                       -
CN                           A*PHI PRIME + B/D*PHI = 0.                  -
CN                                                                       -
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CN              IF NO "COMPOSITION LABEL" IS SUPPLIED (COLS. 7-12),    -
CN              THE CONSTANTS GIVEN APPLY TO ALL COMPOSITIONS SPECIFIED-
CN              ON THE TYPE 10 CARDS.                                  -
CN                                                                     -
CN              IF NO "HIGHER-ENERGY GROUP NUMBER" IS SUPPLIED (COLS.  -
CN              61-66 ARE BLANK), THE CONSTANTS GIVEN APPLY TO ALL     -
CN              ENERGY GROUPS. IF NO "LOWER-ENERGY GROUP NUMBER" IS    -
CN              SUPPLIED (COLS. 67-72 ARE BLANK), THE CONSTANTS GIVEN  -
CN              APPLY TO THE "HIGHER-ENERGY GROUP" ONLY. IF NO GROUP   -
CN              NUMBERS ARE SUPPLIED (COLS. 61-72 ARE BLANK), THE      -
CN              CONSTANTS GIVEN APPLY TO ALL ENERGY GROUPS.            -
CN                                                                     -
CN              DATA ON THIS CARD MAY BE OVERLAYED. THAT IS, CONSTANTS -
CN              DEFINED ON LATER TYPE 11 CARDS SUPERSEDE DATA FOR      -
CN              ENERGY RANGES PREVIOUSLY SPECIFIED.                    -
CN                                                                     -
CN              ANY GROUP FOR WHICH NO INTERNAL BLACK ABSORBER         -
CN              CONDITION CONSTANTS ARE SPECIFIED ON TYPE 11 CARDS     -
CN              WILL BE TREATED AS BEING NON-BLACK.                    -
C                                                                      -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          FINITE-GEOMETRY TRANSVERSE DISTANCES (TYPE 12)             -
C                                                                      -
CL    FORMAT-----(I2,4X,A6,4E12.5)                                     -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     12                                                     -
CD                                                                     -
CD  2   7-12    REGION OR AREA LABEL.                                  -
CD                                                                     -
CD  3   13-24   ACTUAL TRANSVERSE HALF-HEIGHT OR RADIUS.               -
CD                                                                     -
CD  4   25-36   TRANSVERSE EXTRAPOLATION DISTANCE.                     -
CD                                                                     -
CD  5   37-48   ACTUAL TRANSVERSE HALF-HEIGHT IN THE SECOND DIRECTION  -
CD              FOR A FINITE ONE-DIMENSIONAL RECTANGULAR SLAB.         -
CD                                                                     -
CD  6   49-60   TRANSVERSE EXTRAPOLATION DISTANCE IN THE SECOND        -
CD              DIRECTION FOR A FINITE ONE-DIMENSIONAL RECTANGULAR     -
CD              SLAB.                                                  -
C                                                                      -
CN              THE DATA ON THE TYPE 12 CARDS ARE USED TO CALCULATE    -
CN              REGION VOLUMES AND, IN THE ABSENCE OF TYPE 34 CARDS,   -
CN              BUCKLINGS.  REGION VOLUMES ARE CALCULATED USING        -
CN              ACTUAL HALF-HEIGHTS (EXCLUDING THE EXTRAPOLATION       -
CN              DISTANCE).                                             -
CN                                                                     -
CN              AN AREA LABEL IN COLS. 7-12 IMPLIES ALL THE REGIONS    -
CN              ASSIGNED TO THAT AREA.                                 -
CN                                                                     -
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CN              THE REGION-DEPENDENT DATA THAT IS PROVIDED ON THIS     -
CN              CARD IS CONVERTED BY THE GNIP4C INPUT PROCESSOR TO     -
CN              COMPOSITION-DEPENDENT DATA.  THIS IS A POTENTIAL       -
CN              PROBLEM FOR USERS IF THEY HAVE ASSIGNED ONE            -
CN              COMPOSITION TO TWO OR MORE REGIONS WITH DIFFERENT      -
CN              HALF HEIGHTS.                                          -
CN                                                                     -
CN              IF THERE IS NO REGION LABEL (COLS.7-12 ARE BLANK), THE -
CN              DATA ON THE CARD APPLY TO ALL REGIONS OF THE REACTOR.  -
CN              IF THERE IS NO REGION LABEL AND IF THERE ARE NO TYPE 34-
CN              CARD (COMPOSITION AND GROUP DEPENDENT BUCKLING         -
CN              SPECIFICATIONS), THE DATA ON THIS CARD WILL BE USED TO -
CN              CALCULATE A SPACE- AND ENERGY-INDEPENDENT BUCKLING AND -
CN              TO CALCULATE REGION VOLUMES. IN THIS MODE OF INPUT     -
CN              ONLY ONE TYPE 12 CARD SHOULD BE SUPPLIED.              -
CN                                                                     -
CN              IF MORE THAN ONE TYPE 12 CARD IS PRESENT (EACH CARD    -
CN              WITH A VALID REGION OR AREA LABEL IN COLS. 7-12), THE  -
CN              DATA ON THE CARDS WILL BE USED TO CALCULATE REGION     -
CN              VOLUMES.                                               -
CN                                                                     -
CN              DATA ON THIS CARD MAY BE OVERLAYED. THAT IS,           -
CN              TRANSVERSE DISTANCES DEFINED ON LATER TYPE 12          -
CN              CARDS SUPERSEDE DATA FOR REGIONS PREVIOUSLY            -
CN              SPECIFIED.                                             -
CN                                                                     -
CN              IF TYPE 34 CARDS ARE PRESENT, BUCKLINGS WILL BE TAKEN  -
CN              FROM TYPE 34 CARDS AND WILL NOT BE CALCULATED FROM     -
CN              TYPE 12 CARD DATA.  EVEN IF BUCKLINGS ARE TAKEN FROM   -
CN              TYPE 34 CARDS, REGION VOLUMES ARE CALCULATED USING     -
CN              TYPE 12 CARD DATA WHEN TYPE 12 CARDS ARE PRESENT.      -
CN                                                                     -
CN              IN THE ABSENCE OF TYPE 12 AND TYPE 34 CARDS NO         -
CN              BUCKLINGS WILL BE USED AND REGION VOLUMES WILL BE      -
CN              CALCULATED USING UNIT TRANSVERSE HEIGHTS.              -
C                                                                      -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          MATERIAL SPECIFICATIONS (TYPE 13)                          -
C                                                                      -
CL    FORMAT-----(I2,10X,A6,3(A6,E12.5))                               -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     13                                                     -
CD                                                                     -
CD  2   13-18   MATERIAL LABEL (REPEATED ON ADDITIONAL TYPE 13 CARDS). -
CD                                                                     -
CD  3   19-24   UNIQUE ISOTOPE LABEL.                                  -
CD                                                                     -
CD  4   25-36   ISOTOPE ATOM DENSITY (ATOMS/CC * 1.E-24).              -
CD                                                                     -
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CD  5   37-42   UNIQUE ISOTOPE LABEL.                                    -
CD                                                                      -
CD  6   43-54   ISOTOPE ATOM DENSITY (ATOMS/CC * 1.E-24).              -
CD                                                                      -
CD  7   55-60   UNIQUE ISOTOPE LABEL.                                   -
CD                                                                      -
CD  8   61-72   ISOTOPE ATOM DENSITY (ATOMS/CC * 1.E-24).              -
C                                                                       -
CN              MATERIAL LABELS MUST BE NON-BLANK.                      -
CN                                                                      -
CN              MATERIALS CAN BE DEFINED ON A TYPE 13 CARD IN TERMS     -
CN              OF ISOTOPES AND/OR IN TERMS OF OTHER MATERIALS. IN THE  -
CN              LATTER CASE THE "ISOTOPE LABEL" IS A MATERIAL LABEL     -
CN              AND THE "ISOTOPE ATOM DENSITY" IS A VOLUME FRACTION.    -
CN                                                                      -
CN              THE CONCEPT OF MATERIALS DOES NOT EXIST IN THE CCCC     -
CN              ENVIRONMENT, AND THE IDENTITY OF INDIVIDUAL MATERIALS   -
CN              IS LOST WHEN THE CCCC FILES ARE CREATED. TYPE 13        -
CN              CARDS ARE PROVIDED AS AN INPUT CONVENIENCE ONLY.        -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          COMPOSITION SPECIFICATIONS (TYPE 14)                        -
C                                                                       -
CL    FORMAT-----(I2,10X,A6,3(A6,E12.5))                                -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     14                                                      -
CD                                                                      -
CD  2   13-18   COMPOSITION LABEL (REPEATED ON ADDITIONAL TYPE 14       -
CD              CARDS).                                                 -
CD                                                                      -
CD  3   19-24   MATERIAL LABEL.                                         -
CD                                                                      -
CD  4   25-36   MATERIAL VOLUME FRACTION.                              -
CD                                                                      -
CD  5   37-42   MATERIAL LABEL.                                         -
CD                                                                      -
CD  6   43-54   MATERIAL VOLUME FRACTION.                              -
CD                                                                      -
CD  7   55-60   MATERIAL LABEL.                                         -
CD                                                                      -
CD  8   61-72   MATERIAL VOLUME FRACTION.                              -
C                                                                       -
CN              COMPOSITION LABELS MUST BE NON-BLANK.                   -
CN                                                                      -
CN              WHEN A "MATERIAL LABEL" HAS NOT BEEN SPECIFIED          -
CN              (COLS.13-18 OF A TYPE 13 OR TYPE 14 CARD), THE          -
CN              "MATERIAL" WILL BE INTERPRETED AS AN ISOTOPE AND        -
CN              THE "VOLUME FRACTION" WILL BE INTERPRETED AS AN ATOM    -
CN              DENSITY.                                                -
```

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CN                                                                      -
CN              WHEN AN ISOTOPE (OR MATERIAL) IS REFERENCED MORE THAN   -
CN              ONCE FOR A SINGLE COMPOSITION, THE ATOM DENSITIES       -
CN              (OR VOLUME FRACTIONS) ARE SUMMED.                       -
CN                                                                      -
CN              TWO TYPES OF COMPOSITIONS (PRIMARY AND SECONDARY) CAN   -
CN              BE DEFINED ON TYPE 14 CARDS. SECONDARY COMPOSITIONS     -
CN              ARE MIXTURES OF MATERIALS AND/OR ISOTOPES. PRIMARY      -
CN              COMPOSITIONS ARE MIXTURES OF SECONDARY COMPOSITIONS,    -
CN              MATERIALS AND/OR ISOTOPES. ONLY PRIMARY COMPOSITIONS    -
CN              MAY BE ASSIGNED TO REGIONS ON THE TYPE 15 CARDS.        -
CN                                                                      -
CN              SECONDARY COMPOSITIONS ARE TREATED AS CCCC SUBZONES.    -
CN              THOSE CONSTITUENTS OF A PRIMARY COMPOSITION WHICH ARE   -
CN              NOT THEMSELVES SUBZONES (I.E. ISOTOPES AND MATERIALS    -
CN              DIRECTLY ASSIGNED TO PRIMARY COMPOSITIONS) ARE          -
CN              COMBINED INTO CCCC PRIMARY ZONE ASSIGNMENTS.            -
CN                                                                      -
CN              AN EXAMPLE OF A SET OF TYPE 13 AND 14 CARDS             -
CN                                                                      -
CN                13  FUEL1 U238   .020    PU239  .003    O16    .042  -
CN                13  FUEL2 U238   .015    PU239  .004    O16    .042  -
CN                13  SS    FE     .055    CR     .015    NI     .012  -
CN                13  COOL  NA23   .022    SS     0.1                  -
CN                14  MIX1  FUEL1  1.0                                  -
CN                14  MIX2  FUEL1  0.5     FUEL2  0.5                  -
CN                14  COMP1 MIX1   0.4     SS     0.2     COOL   0.4   -
CN                14  COMP2 MIX2   0.4     SS     0.2     COOL   0.4   -
CN                14  COMP3 MIX1   0.2     MIX2   0.2     SS     0.2   -
CN                14  COMP3 COOL   0.2                                  -
CN                14  COMP4 NA23   .022                                 -
CN                                                                      -
CN                    THE MATERIAL COOL IS DEFINED IN TERMS OF AN       -
CN                    ISOTOPE (NA23) AND A MATERIAL (SS).               -
CN                                                                      -
CN                    MIX1 AND MIX2 ARE SECONDARY COMPOSITIONS.         -
CN                    COMP1, COMP2, COMP3 AND COMP4 ARE PRIMARY         -
CN                    COMPOSITIONS.                                     -
CN                                                                      -
CN                    IN THE CCCC FILES MIX1 WILL BE ASSIGNED AS        -
CN                    SUBZONES TO BOTH COMP1 AND COMP3. THE PRIMARY     -
CN                    ZONE ASSIGNMENTS OF COMP1, COMP2 AND COMP3        -
CN                    WILL CONSIST OF SS AND COOL. COMP4 WILL HAVE      -
CN                    NO SUBZONES.                                      -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          ASSIGNMENT OF REGION TO COMPOSITION (CCCC ZONE)             -
CR          (TYPE 15)                                                   -
C                                                                       -
CL    FORMAT-----(I2,4X,11A6)                                           -
C                                                                       -
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CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     15                                                      -
CD                                                                      -
CD  2   7-12    COMPOSITION (CCCC ZONE) LABEL (REPEATED ON ADDITIONAL   -
CD              TYPE 15 CARDS).                                         -
CD                                                                      -
CD  3   13-18   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              CONTAINING SPECIFIED COMPOSITION.                       -
CD                                                                      -
CD  4   19-24   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              CONTAINING SPECIFIED COMPOSITION.                       -
CD                                                                      -
CD  5   25-30   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              CONTAINING SPECIFIED COMPOSITION.                       -
CD                                                                      -
CD  6   31-36   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              CONTAINING SPECIFIED COMPOSITION.                       -
CD                                                                      -
CD  7   37-42   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              CONTAINING SPECIFIED COMPOSITION.                       -
CD                                                                      -
CD  8   43-48   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              CONTAINING SPECIFIED COMPOSITION.                       -
CD                                                                      -
CD  9   49-54   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              CONTAINING SPECIFIED COMPOSITION.                       -
CD                                                                      -
CD  10  55-60   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              CONTAINING SPECIFIED COMPOSITION.                       -
CD                                                                      -
CD  11  61-66   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              CONTAINING SPECIFIED COMPOSITION.                       -
CD                                                                      -
CD  12  67-72   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              CONTAINING SPECIFIED COMPOSITION.                       -
C                                                                       -
CN              AN AREA LABEL IN COLS. 13-72 IMPLIES ALL THE REGIONS    -
CN              ASSIGNED TO THAT AREA.  AREAS ARE DEFINED ON THE        -
CN              TYPE 07 CARD.                                           -
CN                                                                      -
CN              WHEN A PARTICULAR REGION OR AREA IS REFERENCED ON       -
CN              MORE THAN ONE TYPE 15 CARD, THE LAST REFERENCE          -
CN              TO THAT REGION (EITHER DIRECTLY, OR THROUGH AN AREA)    -
CN              ESTABLISHES THE COMPOSITION ASSIGNMENT.                 -
CN              I.E. A REGION/COMPOSITION CORRESPONDENSE ESTABLISHED    -
CN              ON ONE TYPE 15 CARD CAN BE OVERWRITTEN BY A             -
CN              REFERENCE ON A LATER TYPE 15 CARD.                      -
CN                                                                      -
CN              COMPOSITION LABELS MUST BE NON-BLANK.  THE FIRST        -
CN              BLANK REGION LABEL ENCOUNTERED TERMINATES READING       -
CN              OF THE DATA ON THAT PARTICULAR TYPE 15 CARD.            -
CN                                                                      -
CN              ONLY PRIMARY COMPOSITION LABELS (SEE CARD TYPE 14)      -
```

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CN              CAN APPEAR IN COLS. 7-12. PRIMARY COMPOSITIONS ARE     -
CN              EQUIVALENT TO CCCC ZONES. A REGION CAN CONTAIN ONLY    -
CN              ONE PRIMARY COMPOSITION.                               -
CN                                                                     -
CN              WHEN THERE ARE NO TYPE 14 CARDS (THE MACROSCOPIC       -
CN              CROSS SECTIONS ALREADY EXIST) THE COMPOSITION          -
CN              LABEL FIELDS SHOULD CONTAIN COMPOSITION NUMBERS        -
CN              INSTEAD (I2,4X,I6,10A6).                               -
C                                                                      -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          DISTRIBUTED ISOTROPIC INHOMOGENEOUS SOURCE DATA DEFINED    -
CR          EITHER BY REGION OR MESH INTERVAL (TYPE 19)                -
C                                                                      -
CL    FORMAT-----(I2,4X,A6,2I6,4E12.5)                                 -
C                                                                      -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     19                                                     -
CD                                                                     -
CD  2   7-12    LABEL OF REGION OR AREA (BLANK IF DATA ARE GIVEN BY     -
CD              MESH INTERVALS).  IF THE GEOMETRY HAS BEEN SPECIFIED   -
CD              BY AN INPUT GEODST FILE (AND NOT BY A.NIP TYPE 06      -
CD              OR 30 CARDS) USE THE REGION NUMBER (I6) INSTEAD OF     -
CD              THE REGION LABEL.                                      -
CD                                                                     -
CD  3   13-18   HIGHER-ENERGY GROUP NUMBER.                            -
CD                                                                     -
CD  4   19-24   LOWER-ENERGY GROUP NUMBER.                            -
CD                                                                     -
CD  5   25-36   ISOTROPIC SOURCE VALUE IN THE SPECIFIED MESH INTERVAL, -
CD              REGION OR AREA FOR THIS ENERGY RANGE.  (NEUTRONS PER   -
CD              SECOND PER UNIT VOLUME).                               -
CD                                                                     -
CD  6   37-48   LOWER "X" DIRECTION COORDINATE OF MESH INTERVAL        -
CD              CONTAINING THIS SOURCE.                                -
CD                                                                     -
CD  7   49-60   LOWER "Y" DIRECTION COORDINATE OF MESH INTERVAL        -
CD              CONTAINING THIS SOURCE.                                -
C                                                                      -
CD  8   61-72   LOWER Z DIRECTION COORDINATE OF MESH INTERVAL          -
CD              CONTAINING THIS SOURCE.                                -
CD                                                                     -
CN              AN AREA LABEL IN COLS. 7-12 IMPLIES ALL THE REGIONS    -
CN              ASSIGNED TO THAT AREA.                                 -
CN                                                                     -
CN              IF THERE IS NO REGION LABEL (COLS. 7-12 ARE BLANK),    -
CN              THE SOURCE SPECIFIED IN COLS. 25-36 IS PLACED IN THE   -
CN              MESH BOX DEFINED BY COLS. 37-48, 49-60 AND 61-72.      -
CN                                                                     -
CN              IF THERE IS A REGION LABEL (COLS. 7-12 ARE NON-BLANK), -
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CN              THE MESH COORDINATE FIELDS (COLS. 37-48, 49-60 AND     -
CN              61-72) ARE IGNORED AND THE SOURCE SPECIFIED IN COLS.   -
CN              25-36 IS PLACED IN EVERY MESH BOX IN THE REGION.       -
CN                                                                     -
CN              "X" REPRESENTS THE FIRST DIMENSION COORDINATE (X IN    -
CN              X-Y GEOMETRY, R IN R-Z, ETC.). "Y" REPRESENTS THE      -
CN              SECOND DIMENSION COORDINATE (Y IN X-Y GEOMETRY, Z IN   -
CN              R-Z, ETC.). WHEN THE MODEL IS THREE-DIMENSIONAL, THE   -
CN              THIRD DIMENSION IS ALWAYS Z.                           -
C                                                                      -
CN              IN GEOMETRIES INVOLVING AN ANGULAR DIMENSION (THETA)   -
CN              THE ANGULAR VARIABLE MUST BE GIVEN IN RADIANS.         -
CN                                                                     -
CN              IF NO "HIGHER-ENERGY GROUP NUMBER" IS SUPPLIED (COLS.  -
CN              13-18 ARE BLANK), THE SOURCE VALUE GIVEN APPLIES TO    -
CN              ALL ENERGY GROUPS. IF NO "LOWER-ENERGY GROUP NUMBER"   -
CN              IS SUPPLIED (COLS. 19-24 ARE BLANK), THE SOURCE VALUE  -
CN              GIVEN APPLIES TO THE "HIGHER-ENERGY GROUP" ONLY. IF    -
CN              NO GROUP NUMBERS ARE SUPPLIED (COLS. 13-24 ARE BLANK), -
CN              THE SOURCE VALUE GIVEN APPLIES TO ALL ENERGY GROUPS.   -
CN                                                                     -
CN              DATA ON THIS CARD MAY BE OVERLAYED. THAT IS, SOURCE    -
CN              VALUES DEFINED ON LATER TYPE 19 CARDS SUPERSEDE DATA   -
CN              FOR REGIONS AND GROUPS PREVIOUSLY SPECIFIED.           -
CN                                                                     -
CN              AN EDIT OF THE OUTPUT FIXSRC FILE MAY BE OBTAINED BY   -
CN              SUPPLYING THE EDIT SENTINEL ON THE TYPE 40 CARD.       -
C                                                                      -
C----------------------------------------------------------------------


C----------------------------------------------------------------------
CR          SEARCH EDIT OPTIONS AND CONVERGENCE CRITERIA (TYPE 21)     -
C                                                                      -
CL    FORMAT-----(I2,10X,2I6,2E12.5,2I6)                               -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     21                                                     -
CD                                                                     -
CD  2   13-18   SEARCH FILE PROCESSING EDIT SENTINEL                   -
CD                  0, NO EDITS (DEFAULT).                             -
CD                  1, PRINT EDITS.                                    -
CD                  2, WRITE EDITS TO AUXILIARY OUTPUT FILE.           -
CD                  3, WRITE EDITS TO BOTH PRINT AND AUXILIARY OUTPUT  -
CD                     FILE.                                           -
CD                                                                     -
CD  3   19-24   MAXIMUM NUMBER OF SEARCH PASSES (DEFAULT=4).           -
CD                                                                     -
CD  4   25-36   DESIRED KEFF, KEFF(0) (DEFAULT=1.0).                   -
CD                                                                     -
CD  5   37-48   CONVERGENCE CRITERION, EPSILON: RELATIVE ERROR BOUND   -
CD              FOR KEFF (DEFAULT=.01).                                -
CD                                                                     -
```

```
CD              ABSOLUTE VALUE OF ((KEFF-KEFF(0)) / KEFF(0)).LE.       -
CD              EPSILON.                                               -
CD                                                                     -
CD  6   49-54   SEARCH (MODULE) PARAMETER EDIT OPTIONS                 -
CD              ENTER TWO-DIGIT NUMBER (IF) WHERE                      -
CD                                                                     -
CD              I CONTROLS INTERMEDIATE PASS PARAMETER EDITS           -
CD              F CONTROLS FINAL SEARCH PASS PARAMETER EDITS           -
CD                                                                     -
CD              THE INTEGERS I AND F ARE ASSIGNED ONE OF THE           -
CD              FOLLOWING VALUES (LEADING ZEROES ARE IRRELEVANT)       -
CD              0...NO EDITS                                           -
CD              1...PRINT EDITS (DEFAULT FOR F)                        -
CD              2...WRITE EDITS TO AUXILIARY OUTPUT FILE               -
CD              3...WRITE EDITS TO BOTH PRINT AND AUXILIARY OUTPUT FILE-
CD                                                                     -
CD  7   55-60   SEARCH (MODULE) QUANTITY EDIT OPTIONS                 --
CD              ENTER TWO-DIGIT NUMBER (IF) WHERE                      -
CD                                                                     -
CD              I CONTROLS INTERMEDIATE PASS QUANTITY EDITS            -
CD              F CONTROLS FINAL SEARCH PASS QUANTITY EDITS            -
CD                                                                     -
CD              THE INTEGERS I AND F ARE ASSIGNED ONE OF THE           -
CD              FOLLOWING VALUES (LEADING ZEROES ARE IRRELEVANT)       -
CD              0...NO EDITS (DEFAULT)                                 -
CD              1...PRINT EDITS                                        -
CD              2...WRITE EDITS TO AUXILIARY OUTPUT FILE               -
CD              3...WRITE EDITS TO BOTH PRINT AND AUXILIARY OUTPUT FILE-
C                                                                      -
CN              EACH SEARCH PASS REQUIRES THE SUCCESSFUL COMPLETION    -
CN              OF AN EIGENVALUE PROBLEM BY A NEUTRONICS MODULE.       -
CN              SUCCESSFUL NEUTRONICS MODULE COMPLETION IS INDICATED BY-
CN                1.  OUTER ITERATIONS CONVERGED OR                    -
CN                2.  MAXIMUM NUMBER OF OUTER ITERATIONS ATTAINED.     -
C                                                                      -
CN              NONZERO DATA ON THIS CARD OVERRIDES DATA IN AN EXISTING-
CN              SEARCH FILE DURING A SEARCH PROBLEM RESTART.            -
C                                                                      -
C----------------------------------------------------------------------


C----------------------------------------------------------------------
CR          SEARCH PARAMETER DATA (TYPE 22)                            -
C                                                                      -
CL    FORMAT-----(I2,10X,5E12.5)                                       -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     22                                                     -
CD                                                                     -
CD  2   13-24   INITIAL ESTIMATE OF X (DEFAULT=0.0).                   -
CD                                                                     -
CD  3   25-36   SECOND ESTIMATE OF X (IGNORED IF COLS. 61-72 ARE       -
CD              NON-ZERO) (DEFAULT=0.1 (X=0.0), =1.1*X (X NE 0.0))     -
```

```
CD                                                                      -
CD  4   37-48   LOWER BOUND FOR X (DEFAULT=0.0).                        -
CD                                                                      -
CD  5   49-60   UPPER BOUND FOR X (DEFAULT=1.0).                        -
CD                                                                      -
CD  6   61-72   DERIVATIVE OF KEFF WITH RESPECT TO X (OPTIONAL).        -
CN              (PROVIDES AN ALTERNATE METHOD FOR OBTAINING SECOND      -
CN              ESTIMATE OF X IN COLS. 25-36).                          -
C                                                                       -
CN              COLS. 25-36 ARE IGNORED IF COLS. 61-72 CONTAIN OTHER    -
CN              THAN BLANK OR 0.0.                                      -
CN                                                                      -
CN              GENERAL SEARCH EXPRESSION:  P(X) = P(0) + X * M,        -
CN              WHERE P IS THE QUANTITY BEING VARIED, X IS THE SEARCH   -
CN              PARAMETER, AND M IS THE QUANTITY MODIFIER OBTAINED      -
CN              FROM INFORMATION CONTAINED ON ONE OF THE MUTUALLY       -
CN              EXCLUSIVE CARD TYPES 23, 24, 25, OR 26.  X IS TO BE     -
CN              VARIED UNTIL THE DESIRED KEFF IS REACHED.  THE SEARCH   -
CN              WILL BE TERMINATED IF X EXCEEDS ITS BOUNDS OR IF THE    -
CN              MAXIMUM NUMBER OF SEARCH PASSES ARE REACHED.            -
CN              (SOME CODES MAY ALSO TRIGGER JOB TERMINATION BETWEEN    -
CN              SEARCH PASSES IF IT IS ESTIMATED THAT JOB TIME LIMIT    -
CN              WOULD BE EXCEEDED DURING THE NEXT SEARCH PASS).         -
CN                                                                      -
CN              FOR EFFICIENT SEARCHING, SCALE THE SEARCH QUANTITY      -
CN              SUCH THAT THE MAGNITUDES OF THE SEARCH PARAMETER        -
CN              ESTIMATES LIE IN THE INTERVAL (.1,10.)                  -
CN                                                                      -
CN              NONZERO DATA ON THIS CARD OVERRIDES DATA IN AN EXISTING-
CN              SEARCH FILE DURING A SEARCH PROBLEM RESTART.            -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          CONCENTRATION MODIFIERS FOR CRITICALITY SEARCH (TYPE 23)    -
C                                                                       -
CL    FORMAT-----(I2,4X,11A6)                                           -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     23                                                      -
CD                                                                      -
CD  2   7-12    COMPOSITION LABEL OF COMPOSITION (FROM CARD TYPE 14)     -
CD              TO BE USED AS THE MODIFIER M IN THE SEARCH FORMULA.     -
CD                                                                      -
CD  3   13-18   COMPOSITION LABEL OF COMPOSITION (FROM CARD TYPE 14)    -
CD              TO WHICH MODIFIER M IS ADDED AS A SUBZONE.              -
CD                                                                      -
CD  4   19-24   COMPOSITION LABEL OF COMPOSITION (FROM CARD TYPE 14)    -
CD              TO WHICH MODIFIER M IS ADDED AS A SUBZONE.              -
CD                                                                      -
CD  5   25-30   COMPOSITION LABEL OF COMPOSITION (FROM CARD TYPE 14)    -
CD              TO WHICH MODIFIER M IS ADDED AS A SUBZONE.              -
```

```
CD                                                                      -
CD  6    31-36   COMPOSITION LABEL OF COMPOSITION (FROM CARD TYPE 14)    -
CD               TO WHICH MODIFIER M IS ADDED AS A SUBZONE.             -
CD                                                                      -
CD  7    37-42   COMPOSITION LABEL OF COMPOSITION (FROM CARD TYPE 14)    -
CD               TO WHICH MODIFIER M IS ADDED AS A SUBZONE.             -
CD                                                                      -
CD  8    43-48   COMPOSITION LABEL OF COMPOSITION (FROM CARD TYPE 14)    -
CD               TO WHICH MODIFIER M IS ADDED AS A SUBZONE.             -
CD                                                                      -
CD  9    49-54   COMPOSITION LABEL OF COMPOSITION (FROM CARD TYPE 14)    -
CD               TO WHICH MODIFIER M IS ADDED AS A SUBZONE.             -
CD                                                                      -
CD  10   55-60   COMPOSITION LABEL OF COMPOSITION (FROM CARD TYPE 14)    -
CD               TO WHICH MODIFIER M IS ADDED AS A SUBZONE.             -
CD                                                                      -
CD  11   61-66   COMPOSITION LABEL OF COMPOSITION (FROM CARD TYPE 14)    -
CD               TO WHICH MODIFIER M IS ADDED AS A SUBZONE.             -
CD                                                                      -
CD  12   67-72   COMPOSITION LABEL OF COMPOSITION (FROM CARD TYPE 14)    -
CD               TO WHICH MODIFIER M IS ADDED AS A SUBZONE.             -
C                                                                       -
CN               IN THE SEARCH FORMULA  P(X) = P(0) + X * M,            -
CN               P(0) DENOTES THOSE PRIMARY COMPOSITIONS (ZONES,        -
CN               COLS. 13-72) TO WHICH THE MODIFIER COMPOSITIONS (M,    -
CN               COLS. 7-12) ARE ADDED AS SUBZONES,                     -
CN               X IS THE VOLUME FRACTION APPLIED TO THE MODIFIER       -
CN               COMPOSITIONS (CCCC ZONES OR SUBZONES) COMPRISING M,    -
CN               AND P(X) DENOTES THE RESULTANT COMPOSITIONS.           -
CN               CARD TYPE 23 DEFINES P(0) AND M IN TERMS OF COMPOSITION-
CN               LABELS DEFINED ON CARD TYPE 14.                        -
CN                                                                      -
CN               THE MODIFIER COMPOSITION (CCCC ZONE OR SUBZONE) NAME   -
CN               IN COLS. 7-12 MUST BE A SUBZONE OR AN UNASSIGNED (NOT  -
CN               ASSIGNED TO A REGION ON A TYPE 15 CARD) PRIMARY ZONE   -
CN               CONTAINING NO SUBZONES.                                -
CN                                                                      -
CN               THE MODIFIER COMPOSITIONS (M) BECOME SUBZONES OF       -
CN               EACH ZONE SPECIFIED IN COLS. 13-72.  WHEN A SUBZONE IS -
CN               SPECIFIED IN COLS 13-72, THE MODIFIER COMPOSITIONS (M) -
CN               BECOME SUBZONES IN EACH ZONE CONTAINING THE SUBZONE    -
CN               IN COLS. 13-72.  IN BOTH CASES THE VOLUME FRACTION     -
CN               OF THE ADDED SUBZONES IS X.                            -
CN                                                                      -
CN               A MODIFIER COMPOSITION (M) CANNOT MODIFY ANOTHER       -
CN               MODIFIER COMPOSITION OR A COMPOSITION WHICH ALREADY    -
CN               CONTAINS THE MODIFIER COMPOSITION AS A ZONE OR SUBZONE.-
CN                                                                      -
CN               AN EXAMPLE OF A SET OF TYPE 23 CARDS USING THE SAMPLE  -
CN               TYPE 14 CARDS PRESENTED IN THE TYPE 14 CARD DESCRIPTION-
CN               FOLLOWS:                                               -
CN                                                                      -
CN                 23  COMP4 COMP1 MIX2                                 -
CN                 23  MIX1  COMP2                                      -
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CN                                                                      -
CN                    IN THE CCCC FILES COMP4 WILL BECOME A SUBZONE     -
CN                    OF COMP1, COMP2 AND COMP3.  MIX1 WILL BECOME      -
CN                    A SUBZONE OF COMP2.                               -
CN                                                                      -
CN              REPEAT TYPE 23 CARDS AS NEEDED.                         -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          MESH MODIFIERS FOR CRITICALITY SEARCH (TYPE 24)             -
C                                                                       -
CL    FORMAT-----(I2,9X,A1,3E12.5)                                      -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     24                                                      -
CD                                                                      -
CD  2   12      COORDINATE DIRECTION.                                   -
CD              X..."X" COORDINATE DIRECTION.                           -
CD              Y..."Y" COORDINATE DIRECTION.                           -
CD              Z..."Z" COORDINATE DIRECTION.                           -
CD                                                                      -
CD  3   13-24   LOWER (COARSE MESH) COORDINATE.                         -
CD                                                                      -
CD  4   25-36   UPPER (COARSE MESH) COORDINATE.                         -
CD                                                                      -
CD  5   37-48   MESH MODIFIER, M, FOR EACH MESH INTERVAL BETWEEN       -
CD              THE ABOVE COORDINATES.                                  -
C                                                                       -
CN              IN THE SEARCH FORMULA P(X) = P(0) + X * M,              -
CN              P(X) IS THE RESULTING MESH INTERVAL,                    -
CN              P(0) IS THE INITIAL MESH INTERVAL, AND                  -
CN              M IS THE MESH INTERVAL MODIFIER.                        -
CN                                                                      -
CN              DATA ON THIS CARD MAY BE OVERLAYED.  THAT IS MESH       -
CN              MODIFIERS DEFINED ON LATER TYPE 24 CARDS SUPERSEDE      -
CN              DATA FOR REGIONS SPECIFIED PREVIOUSLY.                  -
CN                                                                      -
CN              REPEAT TYPE 24 CARDS AS NEEDED.                         -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR         COMPOSITION DEPENDENT BUCKLING MODIFIERS FOR CRITICALITY     -
CR         SEARCH (TYPE 25)                                             -
C                                                                       -
CL    FORMAT-----(I2,4X,A6,2E12.5)                                      -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     25                                                      -
```

```
CD                                                                      -
CD  2   7-12    COMPOSITION (ZONE) LABEL.                               -
CD                                                                      -
CD  3   13-24   BUCKLING MODIFIER, M, IN FIRST TRANSVERSE DIRECTION.    -
C                                                                       -
CD  4   25-36   BUCKLING MODIFIER, M, IN SECOND TRANSVERSE DIRECTION    -
CD              FOR A FINITE ONE-DIMENSIONAL RECTANGULAR SLAB.          -
C                                                                       -
CN              IN THE SEARCH FORMULA  P(X) = P(0) + X * M,             -
CN              P(X) IS THE RESULTING BUCKLING, P(0) IS THE INITIAL     -
CN              BUCKLING, AND M IS THE BUCKLING MODIFIER.               -
CN              P(0) WILL BE EVALUATED FROM THE TRANSVERSE HEIGHTS      -
CN              GIVEN ON CARD TYPE 12 OR TAKEN DIRECTLY FROM BUCKLINGS -
CN              GIVEN ON CARD TYPE 34.                                  -
CN                                                                      -
CN              IF COLS. 7-12 ARE BLANK, THE DATA IN COLS. 13-24 APPLY -
CN              TO ALL COMPOSITIONS (ZONES) OF THE REACTOR.             -
CN                                                                      -
CN              REPEAT TYPE 25 CARDS AS NEEDED.                         -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          ALPHA MODIFIER FOR CRITICALITY SEARCH (TYPE 26)              -
C                                                                       -
CL    FORMAT-----(I2,10X,E12.5)                                         -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     26                                                      -
CD                                                                      -
CD  2   13-24   ALPHA MODIFIER, M.                                      -
CD                                                                      -
C                                                                       -
CN              IN THE SEARCH FORMULA  P(X) = P(0) + X * M,             -
CN              P(X) IS THE RESULTING ALPHA, P(0) IS THE INITIAL ALPHA,-
CN              AND M IS THE ALPHA MODIFIER.                            -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          HEXAGON DIMENSION (TYPE 29)                                 -
C                                                                       -
CL    FORMAT-----(I2,10X,E12.5,2I6)                                     -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     29                                                      -
CD                                                                      -
CD  2   13-24   DIMENSION OF HEXAGON ACROSS FLATS.                      -
CD                                                                      -
CD  3   25-30   TOTAL NUMBER OF HEXAGONAL RINGS IN THE REGION OF        -
```

```
CD              SOLUTION.                                                -
CD                                                                       -
CD  4   31-36   FOR TRIANGULAR AND TRIANGULAR-Z GEOMETRIES, THE         -
CD              NUMBER OF EQUAL PARTS INTO WHICH EACH SIDE OF THE        -
CD              BASIC EQUILATERAL TRIANGLES MAKING UP THE HEXAGONS ARE -
CD              SUBDIVIDED.  THUS E.G., IF COLS 31-36 CONTAIN 3, THE   -
CD              HEXAGON CONTAINS 54 MESH POINTS INSTEAD OF THE NORMAL  -
CD              6.                                                       -
C                                                                        -
CN              IF THE NUMBER OF RINGS IS NOT PROVIDED IN COLS. 25-30,  -
CN              IT IS DERIVED FROM THE TYPE 30 CARDS.                    -
CN                                                                       -
CN              IF COLS. 31-36 ARE BLANK, THE TRIANGLES ARE NOT          -
CN              SUBDIVIDED.                                              -
CN                                                                       -
CN              THE TYPE 29 CARD IS PERTINENT ONLY IF COLS. 13-18 ON     -
CN              CARD TYPE 03 ARE GREATER THAN OR EQUAL TO 70.            -
CN                                                                       -
CN              FOR TRIANGULAR-Z AND HEXAGONAL-Z GEOMETRIES THE          -
CN              AXIAL (Z) MESH MUST BE SPECIFIED ON TYPE 9 CARDS.        -
C                                                                        -
C-------------------------------------------------------------------------


C-------------------------------------------------------------------------
CR          LOCATIONS OF REGIONS FOR TRIANGULAR, TRIANGULAR-Z,           -
CR          HEXAGONAL, AND HEXAGONAL-Z GEOMETRIES (TYPE 30)              -
C                                                                        -
CL    FORMAT-----(I2,4X,A6,3I6,2E12.5)                                   -
C                                                                        -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                  -
CD  =  =======  ========================================================-
CD  1   1-2     30                                                       -
CD                                                                       -
CD  2   7-12    REGION LABEL (REPEATED ON ADDITIONAL TYPE 30 CARDS).     -
CD                                                                       -
CD  3   13-18   HEXAGONAL RING NUMBER WHERE REGION IS LOCATED.           -
CD                                                                       -
CD  4   19-24   STARTING HEXAGON POSITION FOR THIS REGION.               -
CD                                                                       -
CD  5   25-30   FINAL HEXAGON POSITION FOR THIS REGION.                  -
CD                                                                       -
CD  6   31-42   LOWER Z BOUNDARY OF REGION.                              -
CD                                                                       -
CD  7   43-54   UPPER Z BOUNDARY OF REGION.                              -
CD                                                                       -
C                                                                        -
CN              REGION LABELS MUST BE NON-BLANK.                         -
CN                                                                       -
CN              IF THE STARTING POSITION (COLS. 19-24) IS BLANK OR       -
CN              ZERO, THE REGION LABEL IS ASSIGNED TO THE WHOLE RING.    -
CN                                                                       -
CN              IF THE FINAL POSITION (COLS. 25-30) IS BLANK OR ZERO,    -
CN              THE REGION LABEL IS ASSIGNED TO THE POSITION IN 19-24    -
```

```
CN              OF THE RING IN 13-18.                                          -
CN                                                                             -
CN              DATA ON THIS CARD MAY BE OVERLAYED. THAT IS, REGION            -
CN              ASSIGNMENTS DEFINED ON LATER TYPE 30 CARDS SUPERSEDE           -
CN              DATA FOR RINGS AND POSITIONS PREVIOUSLY SPECIFIED.             -
CN                                                                             -
CN              THE REGION LOWER AND UPPER Z BOUNDARIES MUST COINCIDE          -
CN              WITH MESH LINES, WHICH BOUND MESH INTERVALS.                   -
CN                                                                             -
CN              THE FIGURE BELOW ILLUSTRATES THE ORDER OF NAMING               -
CN              RINGS AND HEXAGONS IN THE RINGS.  THE FIRST NUMBER OF          -
CN              EACH NUMBERED PAIR IS THE RING NUMBER, AND THE SECOND          -
CN              NUMBER IS THE HEXAGON NUMBER IN THAT RING.                     -
CN              THE REGION OF SOLUTION DEPENDS ON THE VALUE IN COLS.           -
CN              13-18 ON CARD TYPE 03 AS FOLLOWS.                              -
CN                                                                             -
CN       COLS. 13-18 ON CARD TYPE 03       REGION OF SOLUTION                  -
CN       ===========================   ============================          -
CN                 80                  ENTIRE FIGURE AS SHOWN BELOW          -
CN                 72                  IN THE 180 DEGREE SECTOR A-B          -
CN                 78                  IN THE 90 DEGREE SECTOR A-C           -
CN                 70                  IN THE 60 DEGREE SECTOR A-D           -
CN                 74                  IN THE 120 DEGREE SECTOR A-E          -
CN                110                  ENTIRE FIGURE AS SHOWN BELOW          -
CN                114                  IN THE 60 DEGREE SECTOR F-C           -
CN                116                  IN THE 120 DEGREE SECTOR F-G          -
CN                                                                             -
CN                      G               E              C                       -
CN                                                                             -
CN                        *             *            *                         -
CN                                                                             -
CN       B                  *           *          *                           -
CN          *                                                        D         -
CN              *              *         *        *               *           -
CN                 *           ======  ======  ======           *             -
CN                    *        =3,5 = =3,4 = =3,3 =         *                 -
CN                       *     ======  ======  ======      *                   -
CN                          ======  ======  ======  ======                     -
CN                          =3,6 = =2,3 = =2,2 = =3,2 =                        -
CN                          ======  ======  ======  ======                     -
CN                       ======  ======  ======  ======  ======                -
CN                       =3,7 = =2,4 = =1,1 = =2,1 = =3,1 =  *  *  *  F        -
CN                       ======  ======  ======  ======  ======                -
CN                          ======  ======  ======  ======                     -
CN                          =3,8 = =2,5 = =2,6 = =3,12=                        -
CN                          ======  ======  ======  ======                     -
CN                             ======  ======  ======      *                   -
CN                             =3,9 = =3,10= =3,11=         *                 -
CN                             ======  ======  ======           *             -
CN                                                                 *           -
CN                                                                    A        -
CN                                                                             -
CN                                                                             -
CN              ALTHOUGH THE REGIONS OF SOLUTION DIFFER FOR THE                -
```

```
CN              TRIANGULAR AND HEXAGONAL GEOMETRY MODELS, TYPE 30      -
CN              CARDS COMPOSED FOR TRIANGULAR GEOMETRY MODELS CAN ALSO -
CN              BE USED FOR HEXAGONAL GEOMETRY MODELS.                 -
CN                                                                     -
C                                                                      -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          BACKGROUND REGION NAME FOR TRIANGULAR, TRIANGULAR-Z,       -
CR          HEXAGONAL, AND HEXAGONAL-Z GEOMETRIES (TYPE 31)            -
C                                                                      -
CL    FORMAT-----(I2,4X,A6)                                           -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     31                                                     -
CD                                                                     -
CD  2   7-12    BACKGROUND REGION NAME.                                -
C                                                                      -
CN              ANY PORTION OF THE REACTOR NOT SPECIFIED ON THE        -
CN              TYPE 30 CARDS WILL BE IN THE BACKGROUND REGION.        -
CN                                                                     -
CN              IF THE BACKGROUND REGION NAME (COLS. 7-12) IS BLANK,   -
CN              OR IF THERE IS NO TYPE 31 CARD, THE BACKGROUND REGION  -
CN              WILL BE ASSIGNED A REGION NUMBER 0 (ZERO).  NOTE THAT  -
CN              SOME CCCC CODES EXCLUDE SUCH A REGION FROM THE REGION  -
CN              OF SOLUTION, WHILE OTHER CCCC CODES MAY NOT ALLOW      -
CN              ZERO REGION NUMBERS.                                   -
C                                                                      -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          COMPOSITION AND GROUP DEPENDENT BUCKLING SPECIFICATIONS    -
CR          (TYPE 34)                                                  -
C                                                                      -
CL    FORMAT-----(I2,4X,A6,2(E12.5,2I6))                              -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     34                                                     -
CD                                                                     -
CD  2   7-12    COMPOSITION LABEL.                                     -
CD                                                                     -
CD  3   13-24   BUCKLING (B**2).                                       -
CD                                                                     -
CD  4   25-30   HIGHER ENERGY BROAD GROUP NUMBER TO WHICH BUCKLING     -
CD              IN COLS. 13-24 APPLIES.                                -
CD                                                                     -
CD  5   31-36   LOWER ENERGY BROAD GROUP NUMBER TO WHICH BUCKLING      -
CD              IN COLS. 13-24 APPLIES.                                -
CD                                                                     -
CD  6   37-48   BUCKLING (B**2).                                       -
```

```
CD                                                                      -
CD  7   49-54   HIGHER ENERGY BROAD GROUP NUMBER TO WHICH BUCKLING     -
CD              IN COLS. 37-48 APPLIES.                                 -
CD                                                                      -
CD  8   55-60   LOWER ENERGY BROAD GROUP NUMBER TO WHICH BUCKLING       -
CD              IN COLS. 37-48 APPLIES.                                 -
C                                                                       -
CN              IF THERE IS NO COMPOSITION LABEL (COLS. 7-12 ARE        -
CN              BLANK), THE BUCKLINGS ON THIS CARD WILL APPLY TO        -
CN              ALL COMPOSITIONS.                                       -
CN                                                                      -
CN              IF NO "HIGHER-ENERGY GROUP NUMBER" IS SUPPLIED IN       -
CN              COLS. 25-30, THE BUCKLING GIVEN IN COLS. 13-24 APPLIES -
CD              TO ALL ENERGY GROUPS.  IF THERE IS A "HIGHER-ENERGY     -
CD              GROUP NUMBER" IN COLS. 25-30, BUT NO "LOWER-ENERGY      -
CD              GROUP NUMBER" IS SUPPLIED IN COLS. 31-36, THE BUCKLING -
CD              GIVEN IN COLS. 13-24 APPLIES TO THE "HIGHER-ENERGY      -
CD              GROUP" ONLY.                                            -
CN                                                                      -
CN              IF NO "HIGHER-ENERGY GROUP NUMBER" IS SUPPLIED IN       -
CN              COLS. 49-54, THE DATA IN COLS. 37-60 ARE IGNORED. IF    -
CN              THERE IS A "HIGHER-ENERGY GROUP NUMBER" IN COLS. 49-54,-
CN              BUT NO "LOWER-ENERGY GROUP NUMBER" IN COLS. 55-60,      -
CN              THE BUCKLING GIVEN IN COLS. 37-48 APPLIES TO THE        -
CN              "HIGHER-ENERGY GROUP" ONLY.                             -
CN                                                                      -
CN              BUCKLINGS CAN BE OVERLAYED. THAT IS, BUCKLINGS DEFINED -
CN              ON LATER TYPE 34 CARDS SUPERSEDE DATA FOR COMPOSITIONS -
CN              AND/OR ENERGY RANGES PREVIOUSLY DEFINED. THE EXCEPTION -
CN              TO THIS RULE IS THE SITUATION DESCRIBED IN THE PRE-     -
CN              CEDING PARAGRAPHS WHERE DATA IS SPECIFICALLY IGNORED.   -
CN                                                                      -
CN              EXAMPLE        34    **  .001  1  3  .002  4  7        -
CN                             34    COMP1  .003  1  5                 -
CN                             34    COMP1  .004  3                    -
CN                             34    COMP2  .005                       -
CN                                                                      -
CN              THIS EXAMPLE IS IN FREE-FORMAT - ** IMPLIES A BLANK     -
CN              LABEL.  COMPOSITION COMP1 IS BUCKLED .003 IN GROUPS     -
CN              1-2, .004 IN GROUP 3, .003 IN GROUPS 4-5, .002 IN       -
CN              GROUPS 6-7, AND ZERO IN ALL OTHER GROUPS.               -
CN              COMPOSITION COMP2 IS BUCKLED .005 IN ALL GROUPS.  ALL   -
CN              OTHER COMPOSITIONS ARE BUCKLED .001 IN GROUPS 1-3,      -
CN              .002 IN GROUPS 4-7 AND ZERO IN ALL OTHER GROUPS.        -
CN                                                                      -
CN              WHEN ANY TYPE 34 CARDS EXIST, BUCKLINGS WILL NOT BE     -
CN              CALCULATED FROM FINITE GEOMETRY DATA ON TYPE 12 CARDS. -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          DIRECTIONAL DIFFUSION COEFFICIENT FACTOR SCHEME (TYPE 35)   -
C                                                                       -
```

```
CL    FORMAT-----(I2,4X,A6,6F6.2,2I6)                                  -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     35                                                     -
CD                                                                     -
CD  2   7-12    DIRECTIONAL DIFFUSION COEFFICIENT FACTOR SCHEME LABEL.  -
CD                                                                     -
CD  3   13-18   FIRST DIMENSION DIFFUSION COEFFICIENT MULTIPLIER, A1.  -
CD                                                                     -
CD  4   19-24   FIRST DIMENSION DIFFUSION COEFFICIENT ADDITIVE         -
CD              TERM, B1.                                              -
CD                                                                     -
CD  5   25-30   SECOND DIMENSION DIFFUSION COEFFICIENT MULTIPLIER, A2. -
CD                                                                     -
CD  6   31-36   SECOND DIMENSION DIFFUSION COEFFICIENT ADDITIVE        -
CD              TERM, B2.                                              -
CD                                                                     -
CD  7   37-42   THIRD DIMENSION DIFFUSION COEFFICIENT MULTIPLIER, A3.  -
CD                                                                     -
CD  8   43-48   THIRD DIMENSION DIFFUSION COEFFICIENT ADDITIVE         -
CD              TERM, B3.                                              -
CD                                                                     -
CD  9   49-54   HIGHER ENERGY BROAD GROUP NUMBER TO WHICH DATA IN      -
CD              COLS. 13-48 APPLY.                                     -
CD                                                                     -
CD  10  55-60   LOWER ENERGY BROAD GROUP NUMBER TO WHICH DATA IN       -
CD              COLS. 13-48 APPLY.                                     -
C                                                                      -
CN              IF MORE THAN ONE TYPE 35 CARD IS NEEDED FOR A GIVEN    -
CN              DIFFUSION COEFFICIENT FACTOR SCHEME, THE LABEL IN      -
CN              COLS. 7-12 MUST BE REPEATED ON EACH ADDITIONAL CARD.   -
CN                                                                     -
CN              FIRST, SECOND AND THIRD DIMENSIONS REFER TO THE        -
CN              DIMENSIONS IN THE ORDER THEY ARE NAMED ON CARD TYPE 3. -
CN              E.G. FOR R-Z GEOMETRY R IS THE FIRST DIMENSION, AND    -
CN              Z IS THE SECOND.                                       -
CN                                                                     -
CN              THE FIRST DIMENSION DIFFUSION COEFFICIENT, D1, IS      -
CN              CALCULATED FROM THE HOMOGENEOUS DIFFUSION COEFFICIENT, -
CN              D, AS FOLLOWS:                                         -
CN                                                                     -
CN                                   D1 = A1*D+B1                      -
CN                                                                     -
CN              THE OTHER TWO DIMENSIONS ARE HANDLED IN A SIMILAR WAY. -
CN                                                                     -
CN              IF THE "HIGHER ENERGY BROAD GROUP NUMBER" IS NOT       -
CN              PROVIDED (COLS. 49-54 ARE BLANK OR ZERO), THE          -
CN              CONSTANTS SPECIFIED IN COLS. 13-48 WILL APPLY TO ALL   -
CN              BROAD GROUPS FOR THE PARTICULAR SCHEME.                -
CN                                                                     -
CN              IF THE "LOWER ENERGY BROAD GROUP NUMBER" IS NOT        -
CN              PROVIDED (COLS. 55-60 ARE BLANK OR ZERO), THE          -
CN              CONSTANTS SPECIFIED IN COLS. 13-48 WILL APPLY TO THE   -
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CN              HIGHER ENERGY BROAD GROUP NUMBER (COLS. 49-54) ONLY.    -
CN                                                                      -
CN              THE CONSTANTS DEFINING A PARTICULAR SCHEME CAN BE       -
CN              OVERLAYED. THAT IS, FACTORS DEFINED ON LATER TYPE 35    -
CN              CARDS SUPERSEDE DATA FOR ENERGY RANGES PREVIOUSLY       -
CN              DEFINED.                                                -
CN                                                                      -
CN              DIRECTIONAL DIFFUSION COEFFICIENT FACTOR SCHEMES ARE    -
CN              ASSIGNED TO COMPOSITIONS ON TYPE 36 CARDS.              -
CN                                                                      -
CN              IF NO TYPE 36 CARDS ARE SUPPLIED, AND ONLY ONE SCHEME   -
CN              IS DEFINED (THE SAME LABEL APPEARS IN COLS. 7-12 OF     -
CN              ALL TYPE 35 CARDS), THE FACTORS WILL BE USED IN ALL     -
CN              COMPOSITIONS.                                           -
CN                                                                      -
CN              IF NO TYPE 36 CARDS ARE SUPPLIED AND MORE THAN ONE      -
CN              SCHEME IS DEFINED, THE FACTORS FOR THE FIRST DEFINED    -
CN              SCHEME (I.E. THAT SCHEME LABEL WHICH APPEARS ON THE     -
CN              FIRST TYPE 35 CARD) WILL BE USED IN ALL COMPOSITIONS.   -
CN                                                                      -
CN              THE CALCULATION OF TRANSVERSE LEAKAGE BY THE DIF3D      -
CN              CODE WILL USE THE THIRD DIMENSION DIFFUSION              -
CN              COEFFICIENT FOR THE PSEUDO ABSORPTION,                  -
CN                     D-B-SQUARED = (A3*D+B3)*B**2                     -
CN              REGARDLESS OF THE PROBLEM DIMENSIONS.  OTHER            -
CN              CODES USING THE COMPXS FILE MAY BEHAVE DIFFERENTLY -    -
CN              IT IS UP TO THE USER TO CHOOSE THE PROPER               -
CN              COEFFICIENT TO MODIFY.                                  -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          DIRECTIONAL DIFFUSION COEFFICIENT FACTORS-COMPOSITION       -
CR          CORRESPONDENCE (TYPE 36)                                    -
C                                                                       -
CL    FORMAT-----(I2,4X,11A6)                                           -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     36                                                      -
CD                                                                      -
CD  2   7-12    DIRECTIONAL DIFFUSION COEFFICIENT FACTOR SCHEME LABEL    -
CD              (SEE CARD TYPE 35).                                     -
CD                                                                      -
CD  3   13-18   COMPOSITION TO WHICH DIFFUSION COEFFICIENT FACTORS ARE  -
CD              ASSIGNED.                                               -
CD                                                                      -
CD  4   19-24   COMPOSITION TO WHICH DIFFUSION COEFFICIENT FACTORS ARE  -
CD              ASSIGNED.                                               -
CD                                                                      -
CD  5   25-30   COMPOSITION TO WHICH DIFFUSION COEFFICIENT FACTORS ARE  -
CD              ASSIGNED.                                               -
CD                                                                      -
```

```
CD  6   31-36   COMPOSITION TO WHICH DIFFUSION COEFFICIENT FACTORS ARE -
CD              ASSIGNED.                                             -
CD                                                                    -
CD  7   37-42   COMPOSITION TO WHICH DIFFUSION COEFFICIENT FACTORS ARE -
CD              ASSIGNED.                                             -
CD                                                                    -
CD  8   43-48   COMPOSITION TO WHICH DIFFUSION COEFFICIENT FACTORS ARE -
CD              ASSIGNED.                                             -
CD                                                                    -
CD  9   49-54   COMPOSITION TO WHICH DIFFUSION COEFFICIENT FACTORS ARE -
CD              ASSIGNED.                                             -
CD                                                                    -
CD  10  55-60   COMPOSITION TO WHICH DIFFUSION COEFFICIENT FACTORS ARE -
CD              ASSIGNED.                                             -
CD                                                                    -
CD  11  61-66   COMPOSITION TO WHICH DIFFUSION COEFFICIENT FACTORS ARE -
CD              ASSIGNED.                                             -
CD                                                                    -
CD  12  67-72   COMPOSITION TO WHICH DIFFUSION COEFFICIENT FACTORS ARE -
CD              ASSIGNED.                                             -
C                                                                     -
CN              IF MORE THAN ONE TYPE 36 CARD IS REQUIRED TO ASSIGN    -
CN              GIVEN DIFFUSION COEFFICIENT FACTORS TO COMPOSITIONS,   -
CN              THE LABEL IN COLS. 7-12 MUST BE REPEATED ON THE        -
CN              ADDITIONAL CARDS.                                     -
CN                                                                    -
CN              IF NO TYPE 36 CARDS ARE SUPPLIED, AND ONLY ONE         -
CN              DIRECTIONAL DIFFUSION COEFFICIENT FACTOR SCHEME IS     -
CN              DEFINED (THE SAME LABEL APPEARS IN COLS. 7-12 OF ALL   -
CN              TYPE 35 CARDS), THE FACTORS WILL BE USED IN ALL        -
CN              COMPOSITIONS.                                         -
CN                                                                    -
CN              IF NO TYPE 36 CARDS ARE SUPPLIED AND MORE THAN ONE     -
CN              SCHEME IS DEFINED, THE FACTORS FOR THE FIRST DEFINED   -
CN              SCHEME WILL BE USED IN ALL COMPOSITIONS.               -
CN                                                                    -
CN              IF NO COMPOSITIONS ARE DEFINED IN COLS. 13-72, THE     -
CN              SCHEME IDENTIFIED BY THE LABEL IN COLS. 7-12 WILL BE   -
CN              USED FOR ALL COMPOSITIONS.                            -
CN                                                                    -
CN              THE SCHEME-COMPOSITION CORRESPONDENCE DATA CAN BE      -
CN              OVERLAYED. THAT IS, DATA GIVEN ON LATER TYPE 36 CARDS  -
CN              SUPERSEDES DATA PREVIOUSLY DEFINED.                   -
C                                                                     -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          FISSION ENERGY CONVERSION FACTOR DATA (TYPE 37)            -
C                                                                     -
CL    FORMAT-----(I2,10X,3(A6,E12.5))                                 -
C                                                                     -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY               -
CD  =  =======  ========================================================-
```

```
CD  1   1-2     37                                                      -
CD                                                                      -
CD  2   13-18   COMPOSITION LABEL.                                      -
CD                                                                      -
CD  3   19-30   ENERGY CONVERSION FACTOR FOR THIS COMPOSITION          -
CD              (FISSIONS/WATT-SEC.).                                   -
CD                                                                      -
CD  4   31-36   COMPOSITION LABEL.                                      -
CD                                                                      -
CD  5   37-48   ENERGY CONVERSION FACTOR FOR THIS COMPOSITION          -
CD              (FISSIONS/WATT-SEC.).                                   -
CD                                                                      -
CD  6   49-54   COMPOSITION LABEL.                                      -
CD                                                                      -
CD  7   55-66   ENERGY CONVERSION FACTOR FOR THIS COMPOSITION          -
CD              (FISSIONS/WATT-SEC.).                                   -
C                                                                       -
CN              IF TYPE 37 OR TYPE 38 CARDS ARE PROVIDED FOR A          -
CN              A PARTICULAR COMPOSITION, THE ENERGY CONVERSION         -
CN              FACTORS IN DATA SET ISOTXS WILL BE IGNORED FOR THAT     -
CN              COMPOSITION, AND THE DATA ON THE TYPE 37 AND TYPE 38    -
CN              CARDS WILL BE USED INSTEAD.                             -
CN                                                                      -
CN              IF THE FIRST LABEL (COLS. 13-18) ON A TYPE 37 CARD IS   -
CN              BLANK, THE ASSOCIATED CONVERSION FACTOR WILL BE         -
CN              ENTERED FOR ALL COMPOSITIONS.                           -
CN                                                                      -
CN              IF COLS. 31-36 ARE BLANK THE DATA IN COLS. 37-66 ARE    -
CN              NEGLECTED.  IF COLS. 49-54 ARE BLANK THE DATA IN        -
CN              COLS. 55-66 ARE NEGLECTED.                              -
CN                                                                      -
CN              DATA ON THIS CARD MAY BE OVERLAYED. THAT IS, FACTORS    -
CN              DEFINED ON LATER TYPE 37 CARDS SUPERSEDE DATA FOR       -
CN              COMPOSITIONS PREVIOUSLY SPECIFIED.                      -
CN                                                                      -
CN              THE ENERGY CONVERSION FACTOR FOR ANY COMPOSITION NOT    -
CN              REFERENCED ON A TYPE 37 OR TYPE 38 CARD WILL BE         -
CN              DETERMINED FROM DATA IN ISOTXS.                         -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          CAPTURE ENERGY CONVERSION FACTOR DATA (TYPE 38)             -
C                                                                       -
CL    FORMAT-----(I2,10X,3(A6,E12.5))                                   -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     38                                                      -
CD                                                                      -
CD  2   13-18   COMPOSITION LABEL.                                      -
CD                                                                      -
CD  3   19-30   ENERGY CONVERSION FACTOR FOR THIS COMPOSITION          -
```

```
CD              (CAPTURES/WATT-SEC.).                                   -
CD                                                                      -
CD  4   31-36   COMPOSITION LABEL.                                      -
CD                                                                      -
CD  5   37-48   ENERGY CONVERSION FACTOR FOR THIS COMPOSITION          -
CD              (CAPTURES/WATT-SEC.).                                   -
CD                                                                      -
CD  6   49-54   COMPOSITION LABEL.                                      -
CD                                                                      -
CD  7   55-66   ENERGY CONVERSION FACTOR FOR THIS COMPOSITION          -
CD              (CAPTURES/WATT-SEC.).                                   -
C                                                                       -
CN              IF TYPE 37 OR TYPE 38 CARDS ARE PROVIDED FOR A          -
CN              A PARTICULAR COMPOSITION, THE ENERGY CONVERSION         -
CN              FACTORS IN DATA SET ISOTXS WILL BE IGNORED FOR THAT     -
CN              COMPOSITION, AND THE DATA ON THE TYPE 37 AND TYPE 38    -
CN              CARDS WILL BE USED INSTEAD.                             -
CN                                                                      -
CN              IF THE FIRST LABEL (COLS. 13-18) ON A TYPE 38 CARD IS   -
CN              BLANK, THE ASSOCIATED CONVERSION FACTOR WILL BE         -
CN              ENTERED FOR ALL COMPOSITIONS.                           -
CN                                                                      -
CN              IF COLS. 31-36 ARE BLANK THE DATA IN COLS. 37-66 ARE    -
CN              NEGLECTED.  IF COLS. 49-54 ARE BLANK THE DATA IN        -
CN              COLS. 55-66 ARE NEGLECTED.                              -
CN                                                                      -
CN              DATA ON THIS CARD MAY BE OVERLAYED. THAT IS, FACTORS    -
CN              DEFINED ON LATER TYPE 38 CARDS SUPERSEDE DATA FOR       -
CN              COMPOSITIONS PREVIOUSLY SPECIFIED.                      -
CN                                                                      -
CN              THE ENERGY CONVERSION FACTOR FOR ANY COMPOSITION NOT    -
CN              REFERENCED ON A TYPE 37 OR TYPE 38 CARD WILL BE         -
CN              DETERMINED FROM DATA IN ISOTXS.                         -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          NUCLIDE SET ASSIGNMENTS (TYPE 39)                           -
C                                                                       -
CL    FORMAT-----(I2,4X,11A6)                                           -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     39                                                      -
CD                                                                      -
CD  2   7-12    NUCLIDE SET LABEL.                                      -
CD                                                                      -
CD  3   13-18   ISOTOPE TO BE ASSIGNED TO THIS NUCLIDE SET.             -
CD                                                                      -
CD  4   19-24   ISOTOPE TO BE ASSIGNED TO THIS NUCLIDE SET.             -
CD                                                                      -
CD  5   25-30   ISOTOPE TO BE ASSIGNED TO THIS NUCLIDE SET.             -
CD                                                                      -
```

```
CD  6   31-36   ISOTOPE TO BE ASSIGNED TO THIS NUCLIDE SET.             -
CD                                                                     -
CD  7   37-42   ISOTOPE TO BE ASSIGNED TO THIS NUCLIDE SET.             -
CD                                                                     -
CD  8   43-48   ISOTOPE TO BE ASSIGNED TO THIS NUCLIDE SET.             -
CD                                                                     -
CD  9   49-54   ISOTOPE TO BE ASSIGNED TO THIS NUCLIDE SET.             -
CD                                                                     -
CD  10  55-60   ISOTOPE TO BE ASSIGNED TO THIS NUCLIDE SET.             -
CD                                                                     -
CD  11  61-66   ISOTOPE TO BE ASSIGNED TO THIS NUCLIDE SET.             -
CD                                                                     -
CD  12  67-72   ISOTOPE TO BE ASSIGNED TO THIS NUCLIDE SET.             -
C                                                                      -
CN              NUCLIDE SET ASSIGNMENTS ARE OPTIONAL. THEIR USE MAY    -
CN              REDUCE THE SIZE OF THE CCCC ATOM DENSITY FILE (ZNATDN) -
CN              AND, THEREFORE, THE RUNNING TIME FOR CROSS SECTION     -
CN              HOMOGENIZATION.                                        -
CN                                                                     -
CN              ALL ISOTOPES USED IN A PARTICULAR ZONE OR A            -
CN              PARTICULAR SUBZONE MUST BE ASSIGNED TO THE SAME        -
CN              NUCLIDE SET.                                           -
CN                                                                     -
CN              WHEN NO TYPE 39 CARDS ARE PROVIDED, ALL ISOTOPES ARE   -
CN              ASSIGNED TO A SINGLE NUCLIDE SET.                      -
C                                                                      -
C----------------------------------------------------------------------


C----------------------------------------------------------------------
CR          SOURCE EDIT AND SYNTHESIS TRIAL FUNCTION SOURCE            -
CR          SPECIFICATION (TYPE 40)                                    -
C                                                                      -
CL    FORMAT-----(I2,4X,4I6)                                           -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     40                                                     -
CD                                                                     -
CD  2   7-12    EDIT FLAG FOR POINTWISE INHOMOGENEOUS SOURCE            -
CD                  0, NO EDITS (DEFAULT).                             -
CD                  1, PRINT EDITS.                                    -
CD                  2, WRITE EDITS TO AUXILIARY OUTPUT FILE.           -
CD                  3, WRITE EDITS TO BOTH PRINT AND AUXILIARY OUTPUT  -
CD                      FILE.                                          -
CD                                                                     -
CD  3   13-18   RTFLUX FILE VERSION NUMBER FOR A SYNTHESIS TRIAL       -
CD              FUNCTION SOURCE.                                       -
CD                    S(X,Y,Z,G)=D(X,Y,Z,G)*FLUX(X,Y,Z,G)             -
CD              WHERE D IS A DIFFUSION COEFFICIENT AND FLUX IS A FLUX  -
CD              (OR ADJOINT FLUX) FROM AN INPUT RTFLUX (OR ATFLUX)     -
CD              FILE.  USE A NEGATIVE VALUE FOR ATFLUX.  SET TO ZERO   -
CD              WHEN ANOTHER TYPE OF SOURCE IS REQUIRED.               -
CD                                                                     -
```

```
CD  4   19-24   VERSION NUMBER OF GEODST FILE SPECIFYING COMPOSITION   -
CD              DISTRIBUTION REQUIRED FOR A SYNTHESIS TRIAL FUNCTION   -
CD              SOURCE.  0 OR 1 IMPLIES THE GEOMETRY DEFINED BY THE    -
CD              CURRENT A.NIP3 DATASET.  THIS PARAMETER IS USED ONLY   -
CD              WHEN THE FLUX FILE VERSION IN COLS. 13-18 IS .GE. 1.   -
CD                                                                     -
CD  5   25-30   WORD LENGTH PARAMETER FOR THE FIXSRC FILE SOURCE       -
CD              DISTRIBUTION.  ON SINGLE-WORD-LENGTH MACHINES          -
CD              (E.G. CDC) THIS INPUT FIELD IS IGNORED.  ON DOUBLE-    -
CD              WORD-LENGTH MACHINES A VALUE OF 1 WILL PRODUCE A       -
CD              SHORT-WORD (I.E. REAL*4) FILE, A VALUE OF 2 WILL       -
CD              PRODUCE A DOUBLE-WORD (I.E. REAL*8) FILE.  THE DIF3D   -
CD              CODE REQUIRES A DOUBLE-WORD FILE  ON DOUBLE-WORD-      -
CD              LENGTH MACHINES.  (DEFAULT = 2 ON DOUBLE-WORD-LENGTH   -
CD              MACHINES)                                              -
C                                                                      -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          NATURAL DECAY INHOMOGENEOUS SOURCE SPECIFICATIONS          -
CR          (TYPE 41)                                                  -
C                                                                      -
CL    FORMAT-----(I2,4X,2(A6,E12.5,A6))                                -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     41                                                     -
C                                                                      -
CD  2   7-12    ISOTOPE LABEL                                          -
CD                                                                     -
CD  3   13-24   DECAY CONSTANT                                         -
CD                                                                     -
CD  4   25-30   SPECTRUM LABEL OF SPECTRUM TO BE USED WITH THIS        -
CD              ISOTOPE (SEE CARD TYPE 42)                             -
CD                                                                     -
CD  5   31-36   ISOTOPE LABEL                                          -
CD                                                                     -
CD  6   37-48   DECAY CONSTANT                                         -
CD                                                                     -
CD  7   49-54   SPECTRUM LABEL OF SPECTRUM TO BE USED WITH THIS        -
CD              ISOTOPE (SEE CARD TYPE 42)                             -
C                                                                      -
CN              WHEN THERE ARE TYPE 41 CARDS A FIXSRC FILE WILL BE     -
CN              CREATED CONTAINING THE DISTRIBUTED SOURCE              -
CN                      S(X,Y,Z,G) = SUM OVER ISOTOPES (I) OF          -
CN                        SCHI(G,I)*DC(I)*ATND(X,Y,Z,I)                -
CN              WHERE SCHI IS AN ISOTOPE SOURCE SPECTRUM (SEE THE TYPE -
CN              42 CARDS), DC IS THE DECAY CONSTANT AND ATND IS THE    -
CN              ISOTOPE NUMBER DENSITY.                                -
CN                                                                     -
CN              AS MANY TYPE 41 CARDS SHOULD BE PROVIDED AS ARE        -
CN              NECESSARY TO SPECIFY ALL ISOTOPES REQUIRED.            -
CN                                                                     -
```

```
CN              WHEN THE SPECTRUM LABEL IS BLANK THE SOURCE WILL BE    -
CN              COMPUTED WITH THE SPECTRUM EQUAL TO 1.0 IN ALL GROUPS. -
C                                                                      -
C----------------------------------------------------------------------


C----------------------------------------------------------------------
CR          SOURCE SPECTRUM DATA (TYPE 42)                             -
C                                                                      -
CL    FORMAT-----(I2,4X,A6,5E12.5)                                     -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     42                                                     -
CD                                                                     -
CD  2   7-12    SPECTRUM LABEL                                         -
CD                                                                     -
CD  3   13-24   GROUP MULTIPLIER (SPECTRUM), FIRST GROUP.              -
CD                                                                     -
CD  4   25-36   GROUP MULTIPLIER (SPECTRUM), NEXT GROUP.               -
CD                                                                     -
CD  5   37-48   GROUP MULTIPLIER (SPECTRUM), NEXT GROUP.               -
CD                                                                     -
CD  6   49-60   GROUP MULTIPLIER (SPECTRUM), NEXT GROUP.               -
CD                                                                     -
CD  7   61-72   GROUP MULTIPLIER (SPECTRUM), NEXT GROUP.               -
C                                                                      -
CN              AS MANY TYPE 42 CARDS, FIVE ENERGY GROUPS PER CARD,    -
CN              SHOULD BE PROVIDED AS ARE NECESSARY TO SPECIFY ALL THE -
CN              SPECTRA NEEDED FOR THE NATURAL DECAY SOURCE            -
CN              CALCULATION.  THE FIRST TYPE 42 CARD MUST HAVE A       -
CN              NON-BLANK SPECTRUM LABEL.  A REPEATED SPECTRUM LABEL   -
CN              IMPLIES A CONTINUATION OF THE LAST CARD WITH THE SAME  -
CN              LABEL.  A BLANK SPECTRUM LABEL IMPLIES A CONTINUATION  -
CN              OF THE SPECTRUM ON THE PREVIOUS TYPE 42 CARD.           -
CN                                                                     -
CN              WHEN THE NUMBER OF DATA FOR A PARTICULAR SPECTRUM IS   -
CN              LESS THAN THE TOTAL NUMBER OF ENERGY GROUPS, THE       -
CN              REMAINING ELEMENTS OF THE SPECTRUM ARE SET TO ZERO.    -
CN              WHEN THE NUMBER OF DATA IS GREATER THAN THE NUMBER     -
CN              OF GROUPS THE SURPLUS ELEMENTS ARE IGNORED.            -
C                                                                      -
C----------------------------------------------------------------------


C----------------------------------------------------------------------
CR          GRAPHICS OUTPUT CONTROL (TYPE 43)                          -
C                                                                      -
CL    FORMAT-----(I2,4X,I6,3E12.4,3I6)                                 -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     43                                                     -
CD                                                                     -
```

```
CD  2    7-12    GRAPHICS OUTPUT SENTINEL FOR MAP                          -
CD               0...NO GRAPHICS (DEFAULT)                                 -
CD               1...GENERATE MAP                                          -
CD                                                                         -
CD  3    13-24   HEIGHT OF GRAPHICS OUTPUT FIELD (DEFAULT=11.0 INCHES)     -
CD                                                                         -
CD  4    25-36   WIDTH OF GRAPHICS OUTPUT FIELD (DEFAULT=11.0 INCHES)      -
CD                                                                         -
CD  5    37-48   FOR TRIANGULAR AND HEXAGONAL GEOMETRIES - THIS FIELD      -
CD               CONTAINS THE FLAT-TO-FLAT DISTANCE ACROSS EACH            -
CD               HEXAGON, IN INCHES (DEFAULT = 0.5 INCHES)                 -
CD                                                                         -
CD               FOR ORTHOGONAL GEOMETRIES - THIS FIELD CONTAINS THE       -
CD               MINIMUM REDUCTION ALLOWED FOR LABELS (DEFAULT = 0.5).     -
CD               SEE THE NOTE BELOW.                                       -
C                                                                          -
CD  6    49-54   PRINTER PLOTTER SENTINEL - HEXAGONAL MAP ONLY            -
CD               1...FLAT-TO-FLAT HEXAGON DIMENSION = 8 ROWS               -
CD               2...FLAT-TO-FLAT HEXAGON DIMENSION = 6 ROWS (DEFAULT)     -
CD                                                                         -
CD  7    55-60   MAXIMUM NO. OF ROWS IN PRINTER-PLOTTER FIELD -            -
CD               HEXAGONAL MAP ONLY (DEFAULT = 48)                         -
CD                                                                         -
CD  8    61-66   MAXIMUM NO. OF PRINT COLUMNS IN PRINTER-PLOTTER FIELD     -
CD               - HEXAGONAL MAP ONLY (DEFAULT = 130)                      -
C                                                                          -
CN               THE GRAPHICS OPTION MAY NOT BE AVAILABLE IN ALL           -
CN               VERSIONS OF THE INPUT PROCESSOR GNIP4C.                   -
CN                                                                         -
CN               THIS CARD CONTROLS THE FORMAT OF THE PRINTER-PLOTTER      -
CN               OUTPUT FOR HEXAGONAL MAPS BUT DOES NOT ACTUALLY           -
CN               TRIGGER THE PRINTER MAP.  THAT IS DONE BY A SENTINEL      -
CN               ON THE TYPE 02 CARD.  THIS CARD HAS NO EFFECT ON THE      -
CN               PRINTER-PLOTTER MAP OF ORTHOGONAL GEOMETRY MODELS.        -
CN                                                                         -
CN               FOR TRIANGULAR AND HEXAGONAL GEOMETRIES THE SCALE         -
CN               OF THE PLOT IS DETERMINED BY THE FLAT-TO-FLAT DISTANCE     -
CN               IN COLS. 37-48.  THE SIZE OF THE GRAPHICS PAGE IS SET     -
CN               BY THE DATA IN COLS. 13-36.  THE CODE GENERATES AS        -
CN               MANY PAGES OF GRAPHICS OUTPUT AS IT TAKES TO COVER THE    -
CN               ENTIRE MAP.  LABELS ARE CENTERED IN EACH HEXAGON, AND     -
CN               THE CHARACTER SIZE IS A FIXED FRACTION (1/8) OF THE       -
CN               FLAT-TO-FLAT DISTANCE.                                    -
CN                                                                         -
CN               FOR ORTHOGONAL GEOMETRIES THE SCALE OF THE PLOT IS        -
CN               SET BY THE CODE SO THAT THE ENTIRE MAP IS FORCED          -
CN               TO FIT IN A SINGLE GRAPHICS PAGE.  THE MAXIMUM            -
CN               SIZE OF THE GRAPHICS PAGE IS SET BY THE DATA IN           -
CN               COLS. 13-36.  LABELS WITH 0.1 INCH CHARACTER HEIGHT       -
CN               ARE PLACE IN REGIONS AS LONG AS THERE IS ROOM.  IF THE    -
CN               REGION IS TOO SMALL, THE LABEL IS REDUCED IN SIZE.  IF    -
CN               TO FIT IN THE REGION THE LABEL SIZE MUST BE REDUCED       -
CN               BY A FACTOR SMALLER THAN THE NUMBER IN COLS. 37-48        -
CN               NO LABEL IS DRAWN.  WHEN THE NUMBER IN COLS. 37-48        -
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CN              IS GREATER THAN 1.0 NO LABELS ARE DRAWN.                -
C                                                                       -
C-----------------------------------------------------------------------

C-----------------------------------------------------------------------
CR          ASSIGNMENT OF REGIONS TO CONTROL ROD BANKS (TYPE 44)        -
C                                                                       -
CL    FORMAT-----(I2,4X,11A6)                                           -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     44                                                      -
CD                                                                      -
CD  2   7-12    CONTROL ROD BANK LABEL (REPEATED ON ADDITIONAL           -
CD              TYPE 44 CARDS IF NECESSARY).                            -
CD                                                                      -
CD  3   13-18   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              AT THE TIP OF THE MOVEABLE PORTION OF THE ROD(S) IN     -
CD              THE SPECIFIED CONTROL ROD BANK.                         -
CD                                                                      -
CD  4   19-24   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              AT THE TIP OF THE MOVEABLE PORTION OF THE ROD(S) IN     -
CD              THE SPECIFIED CONTROL ROD BANK.                         -
CD                                                                      -
CD  5   25-30   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              AT THE TIP OF THE MOVEABLE PORTION OF THE ROD(S) IN     -
CD              THE SPECIFIED CONTROL ROD BANK.                         -
CD                                                                      -
CD  6   31-36   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              AT THE TIP OF THE MOVEABLE PORTION OF THE ROD(S) IN     -
CD              THE SPECIFIED CONTROL ROD BANK.                         -
CD                                                                      -
CD  7   37-42   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              AT THE TIP OF THE MOVEABLE PORTION OF THE ROD(S) IN     -
CD              THE SPECIFIED CONTROL ROD BANK.                         -
CD                                                                      -
CD  8   43-48   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              AT THE TIP OF THE MOVEABLE PORTION OF THE ROD(S) IN     -
CD              THE SPECIFIED CONTROL ROD BANK.                         -
CD                                                                      -
CD  9   49-54   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              AT THE TIP OF THE MOVEABLE PORTION OF THE ROD(S) IN     -
CD              THE SPECIFIED CONTROL ROD BANK.                         -
CD                                                                      -
CD  10  55-60   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              AT THE TIP OF THE MOVEABLE PORTION OF THE ROD(S) IN     -
CD              THE SPECIFIED CONTROL ROD BANK.                         -
CD                                                                      -
CD  11  61-66   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              AT THE TIP OF THE MOVEABLE PORTION OF THE ROD(S) IN     -
CD              THE SPECIFIED CONTROL ROD BANK.                         -
CD                                                                      -
CD  12  67-72   REGION LABEL OR AREA LABEL DEFINING REGION(S)           -
CD              AT THE TIP OF THE MOVEABLE PORTION OF THE ROD(S) IN     -
```

```
CD              THE SPECIFIED CONTROL ROD BANK.                          -
C                                                                        -
CN              ALL REGIONS IN A ROD CHANNEL ABOVE THE ROD TIP           -
CN              MOVE TOGETHER.  ALL REGIONS BELOW THE TIP ARE            -
CN              STATIONARY, AND ARE REPLACED BY ROD REGIONS AS THE       -
CN              ROD MOVES DOWN.  THE TOPMOST REGION IN THE ROD           -
CN              EXPANDS AS THE ROD MOVES DOWN FROM ITS INITIAL           -
CN              POSITION.  THE REGION JUST BELOW THE INITIAL ROD-TIP     -
CN              POSITION EXPANDS AS THE ROD MOVES UP FROM ITS            -
CN              ORIGINAL POSITION.                                       -
CN                                                                       -
CN              THE LOWER BOUNDARY OF ALL ROD-TIP REGIONS WHICH DEFINE   -
CN              RODS ASSIGNED TO A PARTICULAR CONTROL ROD BANK MUST       -
CN              BE AT THE SAME AXIAL POSITION.  "AXIAL" REFERS TO THE    -
CN              Z-DIMENSION IN RZ, XYZ, AND HEX-Z, AND TO THE Y          -
CN              DIMENSION IN XY.  THUS FOR THE (R-Z E.G.) GEOMETRY       -
CN              PICTURED BELOW,                                          -
CN                                                                       -
CN              ----------------------------------------                 -
CN              |       |       |       |       |       |              -
CN              |       |  R2   |       |  R6   |  CR21 |              -
CN              |       |       |       |       |       |              -
CN              |       |-------|  CR11 |-------|-------|              -
CN              |       |       |       |       |       |              -
CN              |       |  R3   |       |       |  CR22 |              -
CN              |       |       |       |       |       |              -
CN              |  R1   |-------|-------|  R7   |-------|              -
CN              |       |       |       |       |       |              -
CN              |       |  R4   |  CR12 |       |  CR23 |              -
CN              |       |       |       |       |       |              -
CN              |       |-------|-------|-------|-------|              -
CN              |       |       |       |       |       |              -
CN              |       |  R5   |  C1   |  R8   |  C2   |              -
CN              |       |       |       |       |       |              -
CN              ----------------------------------------                 -
CN                                                                       -
CN              THE FOLLOWING TYPE 44 CARDS (GIVEN IN FREE FORMAT        -
CN              STYLE INPUT) WOULD RESULT IN A FATAL ERROR               -
CN                                                                       -
CN                    44 BANK1 CR12 CR22                                 -
CN                                                                       -
CN              WHEREAS                                                  -
CN                                                                       -
CN                    44 BANK1 CR12 CR23                                 -
CN                                                                       -
CN              WOULD BE ACCEPTABLE.  ALSO, A ROD BANK MAY NOT BE        -
CN              SPECIFIED USING MORE THAN ONE REGION IN A PARTICULAR     -
CN              VERTICAL CHANNEL.  THUS                                  -
CN                                                                       -
CN                    44 BANK1 CR22 CR23                                 -
CN                                                                       -
CN              WOULD LEAD TO A FATAL INPUT ERROR.                       -
CN                                                                       -
CN              NOTE THAT SINCE IT MUST BE ASSUMED THAT A CONTROL ROD    -
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CN              BANK WILL BE MOVED DURING THE COURSE OF A PROBLEM,     -
CN              AT LEAST ONE REGION MUST BE DEFINED BELOW EACH REGION  -
CN              SPECIFIED IN COLS. 13-72.  THUS, THE FOLLOWING TYPE    -
CN              44 CARD WOULD NOT BE ACCEPTABLE FOR THE GEOMETRY GIVEN -
CN              ABOVE                                                  -
CN                    44 BANK1 C1                                      -
CN                                                                     -
CN              AN AREA LABEL IN COLS. 13-72 IMPLIES ALL THE REGIONS   -
CN              ASSIGNED TO THAT AREA.  AREAS ARE DEFINED ON THE       -
CN              TYPE 07 CARD OF DATASET A.NIP3.                        -
CN                                                                     -
CN              THE FIRST BLANK REGION LABEL ENCOUNTERED TERMINATES    -
CN              READING OF THE DATA ON THAT PARTICULAR TYPE 44 CARD.   -
CN                                                                     -
CN              NOTE THAT A BLANK CONTROL ROD BANK LABEL IS ACCEPTABLE.-
C                                                                      -
C---------------------------------------------------------------------

CEOF
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C*****************************************************************
C                                                                -
C                       Latest version 05/02/02
C                       Current version 1.5 extracted 05/12/15
C                                                                -
CF          A.DIF3D                                              -
CE          ONE-, TWO-, AND THREE-DIMENSIONAL DIFFUSION THEORY   -
CE          MODULE-DEPENDENT BCD INPUT                           -
C                                                                -
CN                      THIS BCD DATASET MAY BE WRITTEN EITHER   -
CN                      IN FREE FORMAT (UNFORM=A.DIF3D) OR       -
CN                      ACCORDING TO THE FORMATS SPECIFIED FOR EACH -
CN                      CARD TYPE (DATASET=A.DIF3D).             -
CN                                                               -
CN                      COLUMNS 1-2 MUST CONTAIN THE CARD TYPE NUMBER. -
CN                                                               -
CN                      A BLANK OR ZERO FIELD GIVES THE DEFAULT OPTION -
CN                      INDICATED.                               -
CN                                                               -
CN                      NON-DEFAULTED DATA ITEMS ON THE A.DIF3D  -
CN                      DATA SET ALWAYS OVERRIDE THE CORRESPONDING -
CN                      DATA ON THE RESTART DATA SET DIF3D.      -
C                                                                -
CN                      THIS FILE DESCRIPTION IS FOR DIF3D/VARIANT 9.0 -
C                                                                -
C*****************************************************************


C-----------------------------------------------------------------
CR          PROBLEM TITLE (TYPE 01)                              -
C                                                                -
CL    FORMAT-----(I2,4X,11A6)                                    -
C                                                                -
CD     COLUMNS          CONTENTS...IMPLICATIONS, IF ANY          -
CD     =======  ========================================================-
CD      1-2     01                                               -
CD                                                               -
CD      7-72    ANY ALPHANUMERIC CHARACTERS (1 CARD ONLY).       -
C                                                                -
C-----------------------------------------------------------------


C-----------------------------------------------------------------
CR          STORAGE AND DUMP SPECIFICATIONS (TYPE 02)            -
C                                                                -
CL    FORMAT-----(I2,4X,3I6)                                     -
C                                                                -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY          -
CD  =  =======  ========================================================-
CD  1   1-2     02                                               -
CD                                                               -
CD  2   7-12    POINTR CONTAINER ARRAY SIZE IN FAST CORE MEMORY (FCM)  -
CD              IN REAL*8 WORDS (DEFAULT=10000).                 -
CD                                                               -
CD  3   13-18   POINTR CONTAINER ARRAY SIZE IN EXTENDED CORE     -
```

```
CD              MEMORY (ECM) IN REAL*8 WORDS (DEFAULT=30000).          -
CD                                                                     -
CD  4   19-24   POINTR DEBUGGING EDIT.                                 -
CD              0...NO DEBUGGING PRINTOUT (DEFAULT).                   -
CD              1...DEBUGGING DUMP PRINTOUT.                           -
CD              2...DEBUGGING TRACE PRINTOUT.                          -
CD              3...BOTH DUMP AND TRACE PRINTOUT.                      -
C                                                                      -
C----------------------------------------------------------------------


C----------------------------------------------------------------------
CR          PROBLEM CONTROL PARAMETERS (TYPE 03)                       -
C                                                                      -
CL    FORMAT-----(I2,4X,11I6)                                          -
C                                                                      -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD  =  =======  ========================================================-
CD  1   1-2     03                                                     -
CD                                                                     -
CD  2   7-12    PROBLEM TYPE.                                          -
CD              0...K-EFFECTIVE PROBLEM (DEFAULT).                     -
CD              1...FIXED SOURCE PROBLEM.                              -
CD                                                                     -
CD  3   13-18   SOLUTION TYPE.                                         -
CD              0...REAL SOLUTION (DEFAULT).                           -
CD              1...ADJOINT SOLUTION.                                  -
CD              2...BOTH REAL AND ADJOINT SOLUTION.                    -
CD                                                                     -
CD  4   19-24   CHEBYSHEV ACCELERATION OF OUTER ITERATIONS.            -
CD              0...YES, ACCELERATE THE OUTER ITERATIONS (DEFAULT).    -
CD              1...NO ACCELERATION.                                   -
CD                                                                     -
CD  5   25-30   MINIMUM PLANE-BLOCK (RECORD) SIZE IN REAL*8 WORDS FOR  -
CD              I/O TRANSFER IN THE CONCURRENT INNER ITERATION         -
CD              STRATEGY. THE DEFAULT (=4500) IS HIGHLY RECOMMENDED.   -
CD                                                                     -
CD  6   31-36   OUTER ITERATION CONTROL.                               -
CD             -4...SAME AS -2, BUT DERIVE LEAKAGE RESULTS             -
CD                 FROM BALANCE EQUATION WITH ZERO RESIDUAL.           -
CD             -3...BYPASS DIF3D MODULE.                               -
CD             -2...CALCULATE DATA MANAGEMENT PARAMETERS AND PERFORM   -
CD                 NEUTRONICS EDITS ONLY.                              -
CD             -1...CALCULATE DATA MANAGEMENT PARAMETERS, CALCULATE    -
CD                 OVERRELAXATION FACTORS AND PERFORM NEUTRONICS       -
CD                 EDITS ONLY.                                         -
CD          .GE.0...MAXIMUM NUMBER OF OUTER ITERATIONS (DEFAULT=30).   -
CD                                                                     -
CD  7   37-42   RESTART FLAG.                                          -
CD              0...THIS IS NOT A RESTART (DEFAULT).                   -
CD              1...THIS IS A RESTART PROBLEM.                         -
CD              2...THIS IS A SPECIAL RESTART FOR VARIANT. IT FORCES   -
CD                  (6) OUTER ITERATION CONTROL ITERATIONS TO ALWAYS   -
CD                  BE PERFORMED. A FULL SWEEP IS ONLY REQUIRED ON THE -
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CD                  LAST OUTER.                                          -
CD                                                                       -
CD  8    43-48   JOB TIME LIMIT, MAXIMUM (CP AND PP(OR WAIT)) PROCESSOR -
CD               SECONDS (DEFAULT=1000000000).                           -
CD                                                                       -
CD  9    49-54   NUMBER OF UPSCATTER ITERATIONS PER OUTER ITERATION      -
CD               (DEFAULT=5).  PERTINENT TO UPSCATTER PROBLEMS ONLY.     -
CD                                                                       -
CD  10   55-60   CONCURRENT ITERATION EFFICIENCY OPTION.                  -
CD               0...PERFORM THE ESTIMATED NO. OF INNER ITERATIONS FOR   -
CD                   EACH GROUP.                                         -
CD               1...AVOID THE LAST PASS OF INNER ITERATIONS IN THOSE    -
CD                   GROUPS FOR WHICH THE NO. OF ITERATIONS IN THE LAST -
CD                   PASS ARE LESS THAN A CODE DEPENDENT THRESHOLD.      -
CD                                                                       -
CD  11   61-66   ACCELERATION OF OPTIMUM OVERRELAXATION FACTOR           -
CD               CALCULATION.                                            -
CD               0...NO ACCELERATION (DEFAULT).                          -
CD               1...ASYMPTOTIC SOURCE EXTRAPOLATION OF POWER ITERATIONS-
CD                   USED TO ESTIMATE THE SPECTRAL RADIUS OF EACH INNER -
CD                   (WITHIN GROUP) ITERATION MATRIX.                    -
CD  12   67-72   OPTIMUM OVERRELAXATION FACTOR ESTIMATION ITERATION      -
CD               CONTROL. THE DEFAULT (=50) IS STRONGLY RECOMMENDED.     -
C                                                                        -
CN               THE MAXIMUM NUMBER OF OUTER ITERATIONS SENTINEL         -
CN               SPECIFIES THE NUMBER OF OUTERS THAT CAN BE PERFORMED    -
CN               (COLS. 31-36) EACH TIME THE DIF3D MODULE IS INVOKED.    -
CN                                                                       -
CN               THE DIF3D TERMINATION PROCEDURE WILL ALWAYS:            -
CN                    1...(RE)WRITE THE APPROPRIATE FLUX FILES           -
CN                        (RTFLUX OR ATFLUX).                            -
CN                    2...(RE)WRITE THE RESTART FILE DIF3D.              -
CN               TO FACILITATE AUTOMATIC RESTART, THE RESTART FLAG       -
CN               ON THE DIF3D RESTART CONTROL FILE WILL BE TURNED ON     -
CN               AUTOMATICALLY UPON DETECTION OF:                        -
CN                    1...MAXIMUM NUMBER OF OUTER ITERATIONS.            -
CN                    2...TIME LIMIT.                                    -
CN                                                                       -
CN                                                                       -
CN               TO RESTART THE FLUX CALCULATION:                        -
CN               EITHER                                                  -
CN                                                                       -
CN                   PROVIDE THE RESTART DATA SET DIF3D AND              -
CN                   THE APPROPRIATE FLUX DATA SET (RTFLUX OR ATFLUX)    -
CN                   AND SPECIFY THEM UNDER "BLOCK=OLD" IN THE BCD       -
CN                   INPUT DATA                                          -
CN               OR                                                      -
CN                    1...SET THE RESTART FLAG (COLS. 37-42) TO 1 ON     -
CN                        THE TYPE 03 CARD. THIS PERMITS IMMEDIATE       -
CN                        RESUMPTION OF OUTER ITERATION ACCELERATION.    -
CN                    2...INCLUDE THE LATEST K-EFFECTIVE ESTIMATE        -
CN                        (COLS. 13-24) AND THE DOMINANCE RATIO          -
CN                        ESTIMATE ON THE TYPE 06 CARD (COLS. 61-72).    -
CN                    3...INCLUDE THE OPTIMUM OVERRELAXATION FACTORS     -
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CN                        FOR EACH GROUP (TYPE 07 CARD).                -
CN                    4...PROVIDE THE APPROPRIATE FLUX DATA SET (RTFLUX -
CN                        OR ATFLUX) AND SPECIFY IT UNDER "BLOCK=OLD"   -
CN                        IN THE BCD INPUT DATA.                        -
CN                                                                      -
CN              A NON-ZERO TIME LIMIT (COLS. 43-48) OVERRIDES           -
CN              THE ACTUAL TIME LIMIT DETERMINED INTERNALLY             -
CN              BY SYSTEM ROUTINES IN THE ANL AND LBL PRODUCTION        -
CN              IMPLEMENTATIONS                                         -
CN                                                                      -
CN              THE TIME LIMIT PARAMETER (COLS. 43-48) IS PERTINENT     -
CN              TO EACH ENTRY TO THE DIF3D MODULE.                      -
CN                                                                      -
CN              IT IS RECOMMENDED THAT AN ODD NUMBER OF UPSCATTER       -
CN              ITERATIONS BE SPECIFIED (COLS. 49-54) TO AVOID          -
CN              ADDITIONAL I/O OVERHEAD.                                -
CN                                                                      -
CN              THE USER IS CAUTIONED TO MONITOR THE POINT-WISE         -
CN              FISSION SOURCE CONVERGENCE TO ENSURE THAT MONOTONIC     -
CN              CONVERGENCE IS OBTAINED WHEN THE EFFICIENCY OPTION      -
CN              (COLS. 55-60) IS ACTIVATED.                             -
CN                                                                      -
CN              THE OPTIMUM OVERRELAXATION FACTOR ACCELERATION OPTION   -
CN              IS PRIMARILY INTENDED FOR PROBLEMS KNOWN TO HAVE HIGH   -
CN              (>1.8) OPTIMUM OVERRELAXATION FACTORS.                  -
CN                                                                      -
CN              ITERATION CONTROL (COLS. 67-72) OF THE OPTIMUM          -
CN              OVERRELAXATION FACTOR ESTIMATION IS PRIMARILY INTENDED  -
CN              FOR USE IN CONJUNCTION WITH THE ASYMPTOTIC ACCELERATION-
CN              OPTION (COLS. 61-66).                                   -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          EDIT OPTIONS (TYPE 04)                                      -
C                                                                       -
CL    FORMAT-----(I2,4X,10I6)                                           -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     04                                                      -
CD                                                                      -
CD  2   7-12    PROBLEM DESCRIPTION EDIT (IN ADDITION TO USER INPUT      -
CD              SPECIFICATIONS WHICH ARE ALWAYS EDITED.                 -
CD              0...NO EDITS (DEFAULT).                                 -
CD              1...PRINT EDITS.                                        -
CD              2...WRITE EDITS TO AUXILIARY OUTPUT FILE.               -
CD              3...WRITE EDITS TO BOTH PRINT AND AUXILIARY OUTPUT FILE-
CD                                                                      -
CD  3   13-18   GEOMETRY (REGION TO MESH INTERVAL) MAP EDIT.            -
CD              0...NO EDITS (DEFAULT).                                 -
CD              1...PRINT EDITS.                                        -
CD              2...WRITE EDITS TO AUXILIARY OUTPUT FILE.               -
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CD              3...WRITE EDITS TO BOTH PRINT AND AUXILIARY OUTPUT FILE-
CD                                                                      -
CD  4   19-24   GEOMETRY (ZONE TO MESH INTERVAL) MAP EDIT.             -
CD              0...NO EDITS (DEFAULT).                                 -
CD              1...PRINT EDITS.                                        -
CD              2...WRITE EDITS TO AUXILIARY OUTPUT FILE.               -
CD              3...WRITE EDITS TO BOTH PRINT AND AUXILIARY OUTPUT FILE-
CD                                                                      -
CD  5   25-30   MACROSCOPIC CROSS SECTION EDIT.                         -
CD              ENTER TWO DIGIT NUMBER SP WHERE                         -
CD                                                                      -
CD              S CONTROLS THE SCATTERING AND PRINCIPAL CROSS SECTIONS -
CD              P CONTROLS THE PRINCIPAL CROSS SECTIONS EDIT ONLY.      -
CD                                                                      -
CD              THE INTEGERS S AND P SHOULD BE ASSIGNED ONE OF THE      -
CD              FOLLOWING VALUES (LEADING ZEROES ARE IRRELEVANT).       -
CD              0...NO EDITS (DEFAULT).                                 -
CD              1...PRINT EDITS.                                        -
CD              2...WRITE EDITS TO AUXILIARY OUTPUT FILE.               -
CD              3...WRITE EDITS TO BOTH PRINT AND AUXILIARY OUTPUT FILE-
CD                                                                      -
CD  6   31-36   BALANCE EDITS                                          -
CD              ENTER 3 DIGIT NUMBER GBR WHERE                          -
CD                                                                      -
CD              G CONTROLS GROUP BALANCE EDITS INTEGRATED OVER THE      -
CD              REACTOR                                                 -
CD              B CONTROLS REGION BALANCE EDIT BY GROUP                 -
CD              R CONTROLS REGION BALANCE EDIT TOTALS                   -
CD                (INCLUDING NET PRODUCTION AND ENERGY MEDIANS)         -
CD                                                                      -
CD              THE INTEGERS G, B, AND R SHOULD BE ASSIGNED ONE OF THE -
CD              FOLLOWING VALUES (LEADING ZEROES ARE IRRELEVANT)        -
CD              0...NO EDITS (DEFAULT).                                 -
CD              1...PRINT EDITS.                                        -
CD              2...WRITE EDITS TO AUXILIARY OUTPUT FILE.               -
CD              3...WRITE EDITS TO BOTH PRINT AND AUXILIARY OUTPUT FILE-
CD                                                                      -
CD  7   37-42   POWER EDITS                                            -
CD              ENTER 2 DIGIT NUMBER RM WHERE                           -
CD                                                                      -
CD              R CONTROLS REGION POWER AND AVERAGE POWER DENSITY EDITS-
CD              M CONTROLS POWER DENSITY BY MESH INTERVAL EDIT (PWDINT)-
CD                                                                      -
CD              THE INTEGERS R AND M SHOULD BE ASSIGNED                 -
CD              ONE OF THE FOLLOWING VALUES (LEADING ZEROES ARE         -
CD              IRRELEVANT)                                             -
CD              0...NO EDITS (DEFAULT).                                 -
CD              1...PRINT EDITS.                                        -
CD              2...WRITE EDITS TO AUXILIARY OUTPUT FILE.               -
CD              3...WRITE EDITS TO BOTH PRINT AND AUXILIARY OUTPUT FILE-
CD                                                                      -
CD  8   43-48   FLUX EDITS                                             -
CD              ENTER 3 DIGIT INTEGER RMB WHERE                         -
CD                                                                      -
```

```
CD              R CONTROLS FLUX EDIT BY REGION AND GROUP                -
CD                INCLUDING GROUP AND REGION TOTALS                     -
CD              M CONTROLS TOTAL (GROUP INTEGRATED) FLUX EDIT           -
CD                BY MESH INTERVAL                                      -
CD              B CONTROLS TOTAL FLUX EDIT BY MESH INTERVAL AND GROUP   -
CD                (RTFLUX OR ATFLUX)                                    -
CD                                                                      -
CD              THE INTEGERS R, M, AND B SHOULD BE ASSIGNED             -
CD              ONE OF THE FOLLOWING VALUES (LEADING ZEROES ARE         -
CD              IRRELEVANT)                                             -
CD              0...NO EDITS (DEFAULT).                                 -
CD              1...PRINT EDITS.                                        -
CD              2...WRITE EDITS TO AUXILIARY OUTPUT FILE.               -
CD              3...WRITE EDITS TO BOTH PRINT AND AUXILIARY OUTPUT FILE-
CD                                                                      -
CD  9   49-54   ZONE AVERAGED (REAL) FLUX EDIT.                         -
CD              0...NO EDITS (DEFAULT).                                 -
CD              1...PRINT EDITS.                                        -
CD              2...WRITE EDITS TO AUXILIARY OUTPUT FILE.               -
CD              3...WRITE EDITS TO BOTH PRINT AND AUXILIARY OUTPUT FILE-
CD                                                                      -
CD  10  55-60   REGION AVERAGED FLUX EDIT.                              -
CD              0...NO EDITS (DEFAULT).                                 -
CD              1...PRINT EDITS.                                        -
CD              2...WRITE EDITS TO AUXILIARY OUTPUT FILE.               -
CD              3...WRITE EDITS TO BOTH PRINT AND AUXILIARY OUTPUT FILE-
CD                                                                      -
CD  11  61-66   INTERFACE FILES TO BE WRITTEN IN ADDITION TO RTFLUX     -
CD              AND/OR ATFLUX.                                          -
CD              ENTER 4 DIGIT INTEGER FSRP WHERE                        -
CD                                                                      -
CD              F CONTROLS WRITING OF SURFACE FAST FLUX TO SFEDIT       -
CD              S CONTROLS WRITING OF SURFACE POWER DENSITY TO SFEDIT   -
CD              R CONTROLS WRITING OF RZFLUX                            -
CD              P CONTROLS WRITING OF PWDINT                            -
CD                                                                      -
CD              THE INTEGERS F, S, R, AND P SHOULD BE ASSIGNED ONE OF   -
CD              THE FOLLOWING VALUES (LEADING ZEROES ARE IRRELEVANT)    -
CD              0...DO NOT WRITE THE INTERFACE FILE                     -
CD              1...WRITE THE INTERFACE FILE (SFEDIT WILL BE WRITTEN    -
CD                  IN REGULAR MESH CELL ORDER)                         -
CD              2...WRITE THE SFEDIT FILE IN REGION ORDER (PERTINENT    -
CD                  TO THE SFEDIT FILE ONLY)                            -
CD                                                                      -
CD  12  67-72   MASTER DIF3D EDIT SENTINEL DURING CRITICALITY SEARCHES -
CD             -1...SUPPRESS ALL DIF3D EDITS EXCEPT THE ITERATION       -
CD                  HISTORY AND ERROR DIAGNOSTICS                       -
CD              0...EDIT INPUT DATA ON 1ST SEARCH PASS, OUTPUT          -
CD                  INTEGRALS UPON CONVERGENCE OR UPON ACHIEVING THE    -
CD                  MAXIMUM SEARCH PASS LIMIT.                          -
CD              N...ALSO INVOKE SPECIFIED DIF3D EDITS EVERY N-TH        -
CD                  SEARCH PASS.                                        -
C                                                                       -
CN              MULTI-DIGIT EDIT SPECIFICATION EXAMPLES.                -
```

```
CN                                                                      -
CN              ENTERING THE INTEGER 201 IN COLUMNS 31-36 YIELDS        -
CN              THE GROUP BALANCE EDIT ON THE AUXILIARY FILE AND        -
CN              THE REGION BALANCE EDIT ON THE PRIMARY PRINT FILE.      -
CN                                                                      -
CN              ENTERING THE INTEGER 30 IN COLUMNS 31-36 YIELDS         -
CN              THE REGION BALANCE EDIT BY GROUP ON BOTH THE PRINT AND  -
CN              THE AUXILIARY OUTPUT FILES.                             -
CN                                                                      -
CN              THE INTERFACE FILE SFEDIT CONTAINS SURFACE- AND         -
CN              CELL-AVERAGED POWER DENSITY AND/OR FAST FLUX DATA       -
CN              BY MESH CELL.  ON OPTION IT IS WRITTEN IN EITHER        -
CN              STANDARD FINE MESH CELL ORDER OR IN REGION ORDER.       -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          CONVERGENCE CRITERIA (TYPE 05)                              -
C                                                                       -
CL    FORMAT-----(I2,10X,3E12.5)                                        -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     05                                                      -
CD                                                                      -
CD  2   13-24   EIGENVALUE CONVERGENCE CRITERION FOR STEADY STATE       -
CD              CALCULATION (DEFAULT VALUE = 1.0E-7 IS RECOMMENDED).    -
CD                                                                      -
CD  3   25-36   POINTWISE FISSION SOURCE CONVERGENCE CRITERION          -
CD              FOR STEADY STATE SHAPE CALCULATION                      -
CD              (DEFAULT VALUE = 1.0E-5 IS RECOMMENDED).                -
CD                                                                      -
CD  4   37-48   AVERAGE FISSION SOURCE CONVERGENCE CRITERION            -
CD              FOR STEADY STATE SHAPE CALCULATION                      -
CD              (DEFAULT VALUE = 1.0E-5 IS RECOMMENDED).                -
C                                                                       -
CN              IN UPSCATTERING PROBLEMS IT IS RECOMMENDED THAT         -
CN              THE EIGENVALUE CONVERGENCE CRITERION (COLS. 13-24)      -
CN              BE .1 TIMES THE POINTWISE FISSION SOURCE CONVERGENCE    -
CN              CRITERION (COLS. 25-36).                                -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          OTHER FLOATING POINT DATA (TYPE 06)                         -
C                                                                       -
CL    FORMAT-----(I2,10X,5E12.5)                                        -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     06                                                      -
CD                                                                      -
```

```
CD  2   13-24   K-EFFECTIVE OF REACTOR (DEFAULT IS OBTAINED FROM       -
CD              THE APPROPRIATE RTFLUX OR ATFLUX FILE, IF PRESENT.    -
CD              OTHERWISE DEFAULT = 1.0).                             -
CD                                                                    -
CD  3   25-36   ANY POINTWISE FISSION SOURCE WILL BE NEGLECTED IN THE -
CD              POINTWISE FISSION SOURCE CONVERGENCE TEST IF IT IS    -
CD              LESS THAN THIS FACTOR TIMES THE R.M.S. FISSION        -
CD              SOURCE (DEFAULT VALUE = .001 IS RECOMMENDED).         -
CD                                                                    -
CD  4   37-48   ERROR REDUCTION FACTOR TO BE ACHIEVED BY EACH SERIES  -
CD              OF INNER ITERATIONS FOR EACH GROUP DURING A SHAPE     -
CD              CALCULATION - STRONGLY RECOMMENDED THAT THE DEFAULT   -
CD              VALUE OF (.04) BE USED.                               -
CD                                                                    -
CD  5   49-60   STEADY STATE REACTOR POWER (WATTS). (DEFAULT = 1.0).  -
CD                                                                    -
CD  6   61-72   DOMINANCE RATIO (FOR RESTART JOBS ONLY).              -
C                                                                     -
CN              K-EFFECTIVE SPECIFICATIONS (COLS. 13-24):             -
CN                   1...FOR K-EFFECTIVE PROBLEMS, SUPPLY ESTIMATED   -
CN                       K-EFFECTIVE OF REACTOR.                      -
CN                   2...FOR RESTARTED K-EFFECTIVE PROBLEMS, SUPPLY   -
CN                       LATEST K-EFFECTIVE ESTIMATE SUPPLIED ON THE  -
CN                       ITERATION HISTORY EDIT.                      -
CN                   3...FOR SOURCE PROBLEMS, SUPPLY K-EFFECTIVE OF   -
CN                       THE REACTOR.                                 -
CN              DEFAULT IS OBTAINED FROM THE APPROPRIATE RTFLUX OR    -
CN              ATFLUX FILE, IF PRESENT.  OTHERWISE DEFAULT=1.0 .     -
C                                                                     -
CN              NON-MONOTONIC POINTWISE FISSION SOURCE CONVERGENCE    -
CN              IS USUALLY INDICATIVE OF THE NEED TO TIGHTEN THE ERROR -
CN              REDUCTION FACTOR(COLS. 37-48).  THIS IS FREQUENTLY TRUE-
CN              IN TRIANGULAR GEOMETRY PROBLEMS WHERE A VALUE OF .01 IS-
CN              USUALLY SUFFICIENT TO OBTAIN MONOTONIC CONVERGENCE.   -
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          OPTIMUM OVERRELAXATION FACTORS (TYPE 07)                  -
C                                                                     -
CL    FORMAT-----(I2,10X,5E12.5)                                      -
C                                                                     -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY               -
CD  =  =======  ========================================================-
CD  1   1-2     07                                                    -
CD                                                                    -
CD  2   13-24   OPTIMUM OVERRELAXATION FACTOR FOR GROUP 1.            -
CD                                                                    -
CD  3   25-36   OPTIMUM OVERRELAXATION FACTOR FOR GROUP 2.            -
CD                                                                    -
CD  4   37-48   OPTIMUM OVERRELAXATION FACTOR FOR GROUP 3.            -
CD                                                                    -
CD  5   49-60   OPTIMUM OVERRELAXATION FACTOR FOR GROUP 4.            -
CD                                                                    -
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CD  6   61-72   OPTIMUM OVERRELAXATION FACTOR FOR GROUP 5.              -
C                                                                       -
CN              REPEAT 5 VALUES PER CARD FOR AS MANY TYPE 07 CARDS      -
CN              AS ARE NEEDED.                                          -
CN                                                                      -
CN              THE OPTIMUM OVERRELAXATION FACTORS ARE NORMALLY         -
CN              OBTAINED FROM THE RESTART INSTRUCTIONS PRINTED          -
CN              IMMEDIATELY AFTER THE DIF3D ITERATION HISTORY EDIT.     -
CN              IN THE RESTART INSTRUCTIONS, THE FACTORS ARE ALWAYS     -
CN              EDITTED IN THE --REAL PROBLEM-- ORDERING AND SHOULD BE  -
CN              ENTERED ON THE TYPE 07 CARD --EXACTLY-- AS EDITTED      -
CN              IN THE RESTART INSTRUCTIONS.                            -
CN                                                                      -
CN              THE PERMISSIBLE FACTOR RANGE IS BOUNDED BY 1.0 AND 2.0  -
CN              INCLUSIVE. A ZERO OR BLANK FACTOR ENTRY DEFAULTS        -
CN              TO 1.0. FACTORS ARE COMPUTED FOR THOSE GROUPS HAVING    -
CN              A FACTOR OF 1.0; FACTORS GREATER THAN 1.0 ARE NOT       -
CN              RECOMPUTED.                                             -
CN                                                                      -
CN              TYPE 07 CARDS ARE PRIMARILY INTENDED FOR RESTART JOBS   -
CN              ONLY (STRONGLY RECOMMENDED).                            -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          NEAR CRITICAL SOURCE PROBLEM ASYMPTOTIC EXTRAPOLATION       -
CR          PARAMETERS (TYPE 08)                                        -
C                                                                       -
CC          ***** WARNING...SELECT THIS OPTION ONLY IF THE  *****       -
CC          ***** ASYMPTOTIC EXTRAPOLATION IS REQUIRED FOR  *****       -
CC          ***** THIS PROBLEM.                             *****       -
C                                                                       -
CL    FORMAT-----(I2,4X,I6,E12.5,I6)                                    -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     08                                                      -
CD                                                                      -
CD  2   7-12    NUMBER OF OUTER (POWER) ITERATIONS PERFORMED PRIOR TO    -
CD              ASYMPTOTIC EXTRAPOLATION OF NEAR CRITICAL SOURCE        -
CD              PROBLEM (DEFAULT=5).                                    -
CD                                                                      -
CD  3   13-24   EIGENVALUE OF THE HOMOGENEOUS PROBLEM CORRESPONDING     -
CD              TO THE NEAR CRITICAL SOURCE PROBLEM. THIS EIGENVALUE    -
CD              MUST BE LESS THAN ONE.                                  -
CD                                                                      -
CD  4   25-30   INITIAL FLUX GUESS SENTINEL.                            -
CD              0...FLAT FLUX GUESS=1.0 (DEFAULT)                       -
CD              1...FLAT FLUX GUESS=0.0                                 -
C                                                                       -
CN              THE TYPE 08 CARD IS REQUIRED TO ACTIVATE AN ALTERNATE   -
CN              SPECIAL ACCELERATION SCHEME FOR NEAR CRITICAL           -
CN              SOURCE PROBLEMS.                                        -
```

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CN                                                                      -
CN              IF COLS. 13-24 ARE ZERO OR BLANK, THE HOMOGENEOUS       -
CN              PROBLEM EIGENVALUE WILL BE ESTIMATED. IN THIS CASE, IT -
CN              IS RECOMMENDED TO INCREASE THE NUMBER OF ITERATIONS IN -
CN              COLS. 7-12 TO AT LEAST 10.                              -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          SN TRANSPORT OPTIONS (TYPE 09)                              -
C                                                                       -
CL    FORMAT-----(I2,4X,2I6,6X,E12.4)                                   -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     09                                                      -
CD                                                                      -
CD  2   7-12    SN ORDER.                                               -
CD                                                                      -
CD  3   13-18   MAXIMUM ALLOWED NUMBER OF LINE SWEEPS PER LINE PER      -
CD              INNER ITERATION (DEFAULT=10).                           -
CD                                                                      -
CD  4   25-36   LINE SWEEP CONVERGENCE CRITERION (DEFAULT=1.0E-4).      -
C                                                                       -
CN              TO INVOKE THE DIF3D TRANSPORT OPTION, THE TYPE 09 CARD -
CN              MUST BE PRESENT WITH A NONZERO SN ORDER. FOR THE TIME   -
CN              BEING, USERS MUST ALSO CONTINUE TO 'PRELIB' TO          -
CN              DATASET 'C116.B99983.MODLIB' TO INVOKE THIS OPTION.     -
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          PARAMETERS FOR NODAL OPTION (TYPE 10)                       -
C                                                                       -
CL    FORMAT-----(I2,4X,7I6)                                            -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     10                                                      -
CD                                                                      -
CD  2   7-12    NODAL APPROXIMATION IN XY-PLANE.                        -
CD              ENTER 3 DIGIT NUMBER LMN WHERE                          -
CD                                                                      -
CD              L DETERMINES WHETHER THIS IS A DIFFUSION OR TRANSPORT   -
CD                CALCULATION.                                          -
CD              M IS THE ORDER OF THE POLYNOMIAL APPROXIMATION TO THE   -
CD                ONE-DIMENSIONAL FLUXES IN THE XY-PLANE.               -
CD              N IS THE ORDER OF THE POLYNOMIAL APPROXIMATION TO THE   -
CD                LEAKAGES TRANSVERSE TO THE X- AND Y-DIRECTIONS.       -
CD                                                                      -
CD              HEXAGONAL GEOMETRY:                                     -
CD              L = 0...(ALWAYS - ONLY DIFFUSION THEORY IS AVAILABLE    -
```

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CD                        IN HEXAGONAL GEOMETRY).                          -
CD              M = 2...NH2 FLUX APPROXIMATION.                            -
CD              M = 3...NH3 FLUX APPROXIMATION.                            -
CD              M = 4...NH4 FLUX APPROXIMATION (DEFAULT).                  -
CD              N = 0...(ALWAYS).                                          -
CD                                                                         -
CD              CARTESIAN GEOMETRY:                                        -
CD              L = 0...DIFFUSION-THEORY OPTION (DEFAULT).                 -
CD              L = 1...TRANSPORT-THEORY OPTION.                           -
CD              M = 2...NX2 (QUADRATIC) FLUX APPROXIMATION.                -
CD              M = 3...NX3 (CUBIC    ) FLUX APPROXIMATION (DEFAULT).      -
CD              M = 4...NX4 (QUARTIC  ) FLUX APPROXIMATION.                -
CD              N = 0...CONSTANT  LEAKAGE APPROXIMATION.                   -
CD              N = 2...QUADRATIC LEAKAGE APPROXIMATION (DEFAULT).         -
CD                                                                         -
CD              LEADING ZEROS ARE IRRELEVANT.                              -
CD              THEREFORE, DEFAULT VALUES FOR MN ARE 40 (HEXAGONAL         -
CD              GEOMETRY) AND 32 (CARTESIAN GEOMETRY).                     -
CD                                                                         -
CD              IF THE TRANSPORT OPTION (L=1) IS SPECIFIED, TRANSPORT      -
CD              THEORY IS USED IN BOTH THE XY-PLANE AND THE AXIAL          -
CD              DIRECTION IN THREE-DIMENSIONAL CARTESIAN GEOMETRY.         -
CD                                                                         -
CD  3   13-18   NODAL APPROXIMATION IN Z-DIRECTION.                        -
CD              ENTER 2 DIGIT NUMBER MN WHERE                              -
CD                                                                         -
CD              M IS THE ORDER OF THE POLYNOMIAL APPROXIMATION TO THE      -
CD                ONE-DIMENSIONAL FLUX IN THE Z-DIRECTION.                 -
CD              N IS THE ORDER OF THE POLYNOMIAL APPROXIMATION TO THE      -
CD                LEAKAGE TRANSVERSE TO THE Z-DIRECTION.                   -
CD                                                                         -
CD              HEXAGONAL AND CARTESIAN GEOMETRIES:                        -
CD              M = 2...NZ2 (QUADRATIC) FLUX APPROXIMATION.                -
CD              M = 3...NZ3 (CUBIC    ) FLUX APPROXIMATION (DEFAULT).      -
CD              M = 4...NZ4 (QUARTIC  ) FLUX APPROXIMATION (CARTESIAN      -
CD                      GEOMETRY ONLY).                                    -
CD              N = 0...CONSTANT  LEAKAGE APPROXIMATION.                   -
CD              N = 2...QUADRATIC LEAKAGE APPROXIMATION (DEFAULT).         -
CD                                                                         -
CD              LEADING ZEROS ARE IRRELEVANT.                              -
CD              THEREFORE, DEFAULT VALUE FOR MN IS 32.                     -
CD                                                                         -
CD  4   19-24   COARSE-MESH REBALANCE ACCELERATION CONTROL.                 -
CD             -1...NO COARSE-MESH REBALANCE ACCELERATION.                 -
CD          .GT.0...NUMBER OF FINE MESH PER REBALANCE MESH IN X- AND       -
CD                  Y-DIRECTIONS - CARTESIAN GEOMETRY ONLY (DEFAULT=4).-
CD                                                                         -
CD  5   25-30   NUMBER OF XY-PLANE PARTIAL CURRENT SWEEPS PER GROUP        -
CD              PER AXIAL MESH SWEEP PER OUTER ITERATION.                  -
CD              (DEFAULT = 0 - LET CODE DECIDE).                           -
CD                                                                         -
CD  6   31-36   NUMBER OF AXIAL PARTIAL CURRENT SWEEPS PER GROUP           -
CD              PER AXIAL PARTIAL CURRENT SWEEP                            -
CD              PER OUTER ITERATION (DEFAULT=2).                           -
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CD                                                                      -
CD  7   37-42   HALF-DOMAIN SYMMETRY FLAG.                              -
CD             -1...DO NOT USE 30 DEGREE (HEXAGONAL GEOMETRY) OR 45     -
CD                 DEGREE (CARTESIAN GEOMETRY) PLANAR SYMMETRY EVEN     -
CD                 IF SUCH SYMMETRY EXISTS.                             -
CD              0...USE 30 DEGREE (HEXAGONAL GEOMETRY) OR 45 DEGREE     -
CD                 (CARTESIAN GEOMETRY) PLANAR SYMMETRY IF SUCH         -
CD                 SYMMETRY EXISTS (DEFAULT).                           -
C                                                                       -
CN              THE NODAL OPTION IS INVOKED IN HEXAGONAL GEOMETRY BY    -
CN              SPECIFYING GEOMETRY-TYPE SENTINELS BETWEEN 110 AND 128  -
CN              ON THE A.NIP3 TYPE 03 CARD.                             -
CN                                                                      -
CD  8   43-48   ASYMPTOTIC SOURCE EXTRAPOLATION SENTINEL.               -
CD              0...PERFORM ASYMPTOTIC SOURCE EXTRAPOLATION ON THE      -
CD                 THE NODAL OUTER ITERATIONS.                          -
CD              1...DO NOT PERFORM ASYMPTOTIC SOURCE EXTRAPOLATION      -
CD                                                                      -
CN              THE NODAL OPTION IS INVOKED IN CARTESIAN GEOMETRY BY    -
CN              SPECIFYING GEOMETRY-TYPE SENTINELS 40 OR 44 ON THE      -
CN              A.NIP3 TYPE 03 CARD AND PROVIDING ANY ACCEPTABLE        -
CN              (E.G. DEFAULT) VALUES ON A.DIF3D TYPE 10 CARD.          -
CN                                                                      -
CN          *** THE CARTESIAN-GEOMETRY NODAL OPTION MAY NOT BE          -
CN              AVAILABLE IN ALL VERSIONS OF DIF3D. ***                 -
C                                                                       -
CN              IT IS IMPORTANT THAT THE NUMBER OF FINE MESH PER        -
CN              REBALANCE MESH BE CHOSEN SUCH THAT THE AVERAGE          -
CN              REBALANCE MESH SPACING IS APPROXIMATELY 30 TO 40 CM IN  -
CN              THE XY-PLANE.  THUS, FOR EXAMPLE, IF THE AVERAGE FINE   -
CN              MESH SPACING IS DELTA CM, THEN THE INTEGER INPUT IN      -
CN              COLS. 19-24 SHOULD BE BETWEEN 30/DELTA AND 40/DELTA.    -
C                                                                       -
CN              IF SLOW (OR DIVERGENT) ITERATIVE CONVERGENCE BEHAVIOR   -
CN              IS OBSERVED, THE NUMBER OF PARTIAL CURRENT SWEEPS       -
CN              SPECIFIED IN COLS. 25-30 AND 31-36 SHOULD BE INCREASED.-
C                                                                       -
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          AXIAL COARSE-MESH REBALANCE BOUNDARIES FOR NODAL            -
CR          OPTION (TYPE 11)                                            -
C                                                                       -
CL    FORMAT-----(I2,10X,3(I6,E12.5))                                   -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD  1   1-2     11                                                      -
CD                                                                      -
CD  2   13-18   NUMBER OF AXIAL COARSE-MESH REBALANCE INTERVALS.        -
CD                                                                      -
CD  3   19-30   UPPER Z-COORDINATE OF THE COARSE-MESH REBALANCE         -
CD              BOUNDARY.                                               -
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CD                                                                      -
CD  4   31-36   NUMBER OF AXIAL COARSE-MESH REBALANCE INTERVALS.       -
CD                                                                      -
CD  5   37-48   UPPER Z-COORDINATE OF THE COARSE-MESH REBALANCE        -
CD              BOUNDARY.                                               -
CD                                                                      -
CD  6   49-54   NUMBER OF AXIAL COARSE-MESH REBALANCE INTERVALS.       -
CD                                                                      -
CD  7   55-66   UPPER Z-COORDINATE OF THE COARSE-MESH REBALANCE        -
CD              BOUNDARY.                                               -
C                                                                       -
CN              THE TYPE 11 CARD IS PERTINENT ONLY WHEN THE THREE-      -
CN              DIMENSIONAL NODAL OPTION (A.NIP3 TYPE 03 GEOMETRY-TYPE -
CN              SENTINEL VALUE EQUAL TO 44 OR BETWEEN 120 AND 128) IS  -
CN              SPECIFIED.                                              -
CN                                                                      -
CN              IF NO TYPE 11 CARDS ARE PRESENT, THE AXIAL COARSE-MESH -
CN              REBALANCE BOUNDARIES ARE DEFINED BY THE AXIAL COARSE-  -
CN              MESH BOUNDARIES OBTAINED FROM THE GEODST FILE.  THESE  -
CN              BOUNDARIES IN TURN ARE ANY BOUNDARY POSITIONS SPECIFIED-
CN              ON THE DATASET A.NIP3 TYPE 09 OR 30 CARDS.              -
CN                                                                      -
CN              AXIAL COARSE-MESH REBALANCE BOUNDARIES MUST BE SELECTED-
CN              FROM THE SET OF COARSE-MESH BOUNDARIES CONTAINED IN THE-
CN              GEODST FILE, AS DETERMINED BY THE COARSE-MESH           -
CN              BOUNDARIES WHICH ARE EXPLICITLY MENTIONED ON THE        -
CN              DATASET A.NIP TYPE 09 OR 30 CARDS.                      -
CN                                                                      -
CN              BOUNDARIES ARE SPECIFIED VIA NUMBER PAIRS.              -
CN              EACH NUMBER PAIR IS OF THE FORM (N(I), Z(I)). THERE     -
CN              ARE N(I) AXIAL COARSE-MESH REBALANCE INTERVALS BETWEEN -
CN              Z(I-1) AND Z(I), WHERE Z(0) IS THE LOWER REACTOR        -
CN              BOUNDARY IN THE Z-DIRECTION. NUMBER PAIRS MUST BE       -
CN              GIVEN IN ORDER OF INCREASING MESH COORDINATES. ALL      -
CN              AXIAL COARSE-MESH REBALANCE BOUNDARIES MUST COINCIDE    -
CN              WITH THE MESH LINES WHICH BOUND MESH INTERVALS.         -
C                                                                       -
C-----------------------------------------------------------------------

C-----------------------------------------------------------------------
CR          PARAMETERS FOR VARIATIONAL NODAL OPTION (TYPE 12)           -
C                                                                       -
CL    FORMAT-----(I2,4X,11I6)                                           -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  =======================================================-
CD  1   1-2     12                                                      -
CD                                                                      -
CD  2   7-12    NODAL SPATIAL APPROXIMATION.                            -
CD              ENTER ONE OF THE FOLLOWING                              -
CD              LMN = CLASSICAL VARIANT                                 -
CD              LLMMXN = NEW VARIANT INPUT STYLE                        -
CD                                                                      -
CD              L IS THE ORDER OF THE POLYNOMIAL APPROXIMATION OF THE   -
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CD              SOURCE WITHIN THE NODE.                                  -
CD              M IS THE ORDER OF THE POLYNOMIAL APPROXIMATION OF THE    -
CD              FLUXES WITHIN THE NODE.                                  -
CD              N IS THE ORDER OF THE POLYNOMIAL APPROXIMATION OF THE    -
CD              LEAKAGES ON THE SURFACES OF THE NODES.                   -
CD              X IS THE ORDER REDUCTION TO BE APPLIED IN THE Z          -
CD              DIRECTION. FOR A FULLY MTH ORDER APPROXIMATION           -
CD              USE 0.                                                   -
CD                                                                       -
CD              HEXAGONAL AND CARTESIAN GEOMETRY:                        -
CD              L = 1... LINEAR SOURCE APPROXIMATION.                    -
CD              L = 2... QUADRATIC SOURCE APPROXIMATION.                 -
CD              L > 2... LTH ORDER SOURCE APPROXIMATION.                 -
CD              M = 1... LINEAR FLUX APPROXIMATION.                      -
CD              M = 2... QUADRATIC FLUX APPROXIMATION.                   -
CD              M > 2... MTH ORDER FLUX APPROXIMATION.                   -
CD              N = 0... FLAT LEAKAGE APPROXIMATION.                     -
CD              N = 1... LINEAR LEAKAGE APPROXIMATION (DEFAULT).         -
CD              N > 1... NTH ORDER LEAKAGE APPROXIMATION.                -
CD              X >=0... ORDER REDUCTION IN THE Z DIRECTION              -
CD                                                                       -
CD              LEADING ZEROS ARE IRRELEVANT.                            -
CD              DEFAULT VALUES ARE L=N+1 M=4 N=1, LLMMXN= 20401          -
CD                                                                       -
CD              FOR CLASSICAL VARIANT STYLE 3-D INPUT:                   -
CD              X = 1 WHEN M = 5 AND X = 2 WHEN M > 5                    -
CD              FOR HEXAGONAL GEOMETRY IT IS SUGGESTED THAT M >= 5       -
CD                                                                       -
CD  3   13-18   ANGULAR APPROXIMATION.                                   -
CD              ENTER ONE OF THE FOLLOWING THREE OPTIONS                 -
CD              MN = CLASSICAL VARIANT INPUT STYLE                       -
CD              MMNN = UPDATED VARIANT INPUT STYLE                       -
CD              HMMNN = NEW VARIANT INPUT STYLE                          -
CD                                                                       -
CD              H IS THE PN ANGULAR TRIAL FUNCTION SET TO USE (1 OR 3)   -
CD              M IS THE ORDER OF THE PN EXPANSION OF THE FLUX.          -
CD              N IS THE ORDER OF THE PN EXPANSION OF THE LEAKAGE.       -
CD                                                                       -
CD              HEXAGONAL AND CARTESIAN GEOMETRIES:                      -
CD              H = 1... STANDARD FUNCTIONS, CIRCA 1992 (DEFAULT).       -
CD              H = 3... YANG FUNCTIONS, CIRCA 2002.                     -
CD              M = 1... P1 FLUX EXPANSION.                              -
CD              M = 3... P3 FLUX EXPANSION (DEFAULT).                    -
CD              M > 3... PM FLUX EXPANSION, M MUST BE ODD                -
CD              N = 1... P1 LEAKAGE EXPANSION.                           -
CD              N = 3... P3 LEAKAGE EXPANSION (DEFAULT).                 -
CD              N > 3... PN LEAKAGE EXPANSION, N MUST BE ODD             -
CD                                                                       -
CD              M MUST EQUAL N, REDUCED ORDER 31 WAS OBSOLETE.           -
CD              DEFAULT VALUE IS 10303. DIFFUSION IS 11=0101=10101       -
CD                                                                       -
CD              EXAMPLES: 77=0707=10707 ; 30909 ; -9999 ; 11111          -
CD                                                                       -
CD              IF MN IS NEGATIVE, SIMPLIFIED SPHERICAL HARMONICS(SPN)   -
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CD              ARE USED (EXAMPLE -33=-0303=-10303).                    -
CD              YANG FUNCTIONS DO NOT APPLY TO SPN                      -
CD                                                                      -
CD  4   19-24   COARSE-MESH REBALANCE ACCELERATION CONTROL.             -
CD             -1...NO COARSE-MESH REBALANCE ACCELERATION.              -
CD          .GT.0...NUMBER OF FINE MESH PER REBALANCE MESH IN X- AND    -
CD                  Y-DIRECTIONS - CARTESIAN GEOMETRY ONLY (DEFAULT=6).-
CD                                                                      -
CD  5   25-30   NUMBER OF XY-PLANE PARTIAL CURRENT SWEEPS PER GROUP     -
CD              PER AXIAL MESH SWEEP PER OUTER ITERATION.               -
CD              (DEFAULT = 0 - LET CODE DECIDE).                        -
CD                                                                      -
CD  6   31-36   NUMBER OF AXIAL PARTIAL CURRENT SWEEPS PER GROUP        -
CD              PER AXIAL PARTIAL CURRENT SWEEP                         -
CD              PER OUTER ITERATION (DEFAULT=0 - LET CODE DECIDE)       -
CD                                                                      -
CD  7   37-42   HALF-DOMAIN SYMMETRY FLAG.                             -
CD             -1...DO NOT USE 30 DEGREE (HEXAGONAL GEOMETRY) OR 45     -
CD                  DEGREE (CARTESIAN GEOMETRY) PLANAR SYMMETRY EVEN    -
CD                  IF SUCH SYMMETRY EXISTS.                            -
CD              0...USE 30 DEGREE (HEXAGONAL GEOMETRY) OR 45 DEGREE     -
CD                  (CARTESIAN GEOMETRY) PLANAR SYMMETRY IF SUCH        -
CD                  SYMMETRY EXISTS (DEFAULT).                          -
C                                                                       -
CN              THE NODAL OPTION IS INVOKED IN HEXAGONAL GEOMETRY BY    -
CN              SPECIFYING GEOMETRY-TYPE SENTINELS BETWEEN 110 AND 128  -
CN              ON THE A.NIP3 TYPE 03 CARD.                             -
CN                                                                      -
CD  8   43-48   ASYMPTOTIC SOURCE EXTRAPOLATION SENTINEL.               -
CD             -1...PERFORM ASYMPTOTIC SOURCE EXTRAPOLATION ON THE      -
CD                  NODAL OUTER ITERATIONS ONLY ON FISSION SOURCES.     -
CD                  NO EXTRA-SPACE IS NEEDED TO STORE PREVIOUS OUTER    -
CD                  ITERATION CURRENTS.                                 -
CD              0...PERFORM ASYMPTOTIC SOURCE EXTRAPOLATION ON THE      -
CD                  NODAL OUTER ITERATIONS ON FISSION SOURCES AND       -
CD                  CURRENTS.                                           -
CD              1...DO NOT PERFORM ASYMPTOTIC SOURCE EXTRAPOLATION      -
CD                                                                      -
CD  9   49-54   ANISOTROPIC SCATTERING APPROXIMATION NPNO.             -
CD              0...ISOTROPIC SCATTERING (DEFAULT).                     -
CD              N...ANISOTROPIC SCATTERING ORDER (.LE.3).               -
CD                  N MUST BE LESS THAN OR EQUAL TO MAXORD, MAXIMUM     -
CD                  ANISOTROPIC ORDER SPECIFIED IN ISOTXS OR COMPXS     -
CD                  FILES.                                              -
CD                                                                      -
CD 10   55-60   EXTENDED TRANSPORT APPROXIMATION (NXTR) ON TOTAL        -
CD              CROSS SECTION.                                          -
CD             -1...IF NPNO .EQ. 0 USE TOTAL CROSS SECTION PROVIDED     -
CD                  IN COMPXS FILE, OTHERWISE USE TRANSPORT CROSS       -
CD                  SECTION INSTEAD OF TOTAL ONE.                       -
CD              0...(DEFAULT).                                          -
CD                  IF NPNO .EQ. 0 USE TRANSPORT CROSS SECTION          -
CD                  PROVIDED IN COMPXS FILE.                            -
CD                  IF NPNO .GT. 0 AND NPNO .EQ. MAXORD USE TOTAL       -
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CD                  CROSS SECTION PROVIDED IN COMPXS FILE.              -
CD                  IF NPNO .GT. 0 AND NPNO .LT. MAXORD CORRECT TOTAL   -
CD                  CROSS SECTION PROVIDED IN COMPXS FILE WITH          -
CD                  EXTENDED TRANSPORT APPROXIMATION TAKING INTO        -
CD                  ACCOUNT THE NPNO + 1 ORDER SCATTERING CROSS         -
CD                  SECTIONS (BHS APPROXIMATION).                       -
CD              N...IF NXTR .LE. NPNO USE TOTAL CROSS SECTION.          -
CD                  IF NXTR .GT. NPNO PERFORM EXTENDED TRANSPORT        -
CD                  APPROXIMATION ON TOTAL CROSS SECTION FROM NPNO + 1  -
CD                  TO NXTR ORDER.                                      -
CD                                                                      -
CD 11   61-66   OMEGA TRANSFORMATION ACCELERATION OPTION.               -
CD              0...OMEGA TRANSFORMATION ACCELERATION IS APPLIED. IN    -
CD                  THIS CASE THE NUMBER OF INNER ITERATIONS PER GROUP  -
CD                  CALCULATED BY THE CODE IS SIGNIFICANTLY LESS THAN   -
CD                  THE STANDARD CASE.                                  -
CD              1...OMEGA TRANSFORMATION ACCELERATION IS NOT APPLIED.    -
CD                                                                      -
CD 12   67-72   RADIAL INNER ITERATION ALGORITHM.                        -
CD              0...PARTITIONED MATRIX ALGORITHM (DEFAULT).             -
CD              1...FULL MATRIX ALGORITHM. THIS ALGORITHM IS SOMETIMES  -
CD                  NECESSARY WITH VERY SMALL NODE MESH SIZE WHERE      -
CD                  DIVERGENCE CAN OCCUR. THIS ALGORYTHM REQUIRES A     -
CD                  SIGNIFICANTLY LARGER COMPUTATIONAL TIME.            -
CD                  FULL MATRIX ALGORYTHM IS IMPOSED WHEN ONLY ONE      -
CD                  OUTER ITERATION IS SPECIFIED (FIXED SOURCE          -
CD                  PROBLEM WITHOUT FISSION EVENTS).                    -
CD              N...IF A POSITIVE NUMBER N GREATER THAN 1 AND SMALLER   -
CD                  THAN THE TOTAL NUMBER OF INNER ITERATIONS IS        -
CD                  SPECIFIED, THE FULL MATRIX ALGORITHM IS APPLIED     -
CD                  WITH FREQUENCY N DURING THE INNER ITERATIONS.       -
CD                  IF N GREATER OR EQUAL TO THE TOTAL NUMBER OF INNER  -
CD                  ITERATION FOR THE GROUP THE PARTITIONED MATRIX      -
CD                  ALGORITHM IS APPLIED.                               -
CD                                                                      -
CR          PARAMETERS FOR VARIATIONAL NODAL OPTION (TYPE 12)           -
CR                          (CONTINUATION)                              -
C                                                                       -
CL    FORMAT-----(I2,4X,3I6)                                            -
C                                                                       -
CD  #  COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                 -
CD  =  =======  ========================================================-
CD 13   1-2     12                                                      -
CD                                                                      -
CD 14   7-12    NHFLUX CONTENT                                          -
CD              0...BOTH FLUXES AND PARTIAL CURRENTS ARE STORED ON      -
CD                  NHFLUX FILE                                         -
CD              1...ONLY FLUXES ARE STORED ON NHFLUX FILE               -
CD              2...ONLY PARTIAL CURRENTS ARE STORED ON NHFLUX FILE     -
CD                                                                      -
CD 15   13-18   PERTURBATION OPTION                                     -
CD              0...NO EFFECT                                           -
CD              1...ANGULAR AND SPATIAL APPROXIMATION FOR SOURCE        -
CD                  EXPANSION ARE SET EQUAL TO THE ONES USED FOR THE    -
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CD                  FLUX. THIS IS NEEDED FOR STORING ON NHFLUX A       -
CD                  COMPLETE EXPANSION OF THE FLUX MOMENTS. AS A       -
CD                  CONSEQUENCE SLIGHTLY DIFFERENCES WILL BE OBSERVED  -
CD                  IN THE RESULTS COMPARED AGAINST A LESS ACCURATE    -
CD                  EXPANSION OF THE SOURCE.                           -
CD                                                                     -
CD                                                                     -
CD 16   19-24   HARMONIC CALCULATION                                    -
CD              N...THE NTH HARMONIC WILL BE CALCULATED (0 IS THE      -
CD                  FUNDAMENTAL MODE). NOT YET OPERATIONAL.            -
CD                                                                     -
CN              IN FREE FORMAT THE NODAL VARIATIONAL PARAMETERS ARE    -
CN              PROVIDED ONLY IN ONE CARD OF TYPE 12. ADDITIONAL TYPE  -
CN              12 CARDS WILL BE IGNORED.                              -
CN              IN FIXED FORMAT, IF THE CONTINUATION CARD OF TYPE 12   -
CN              IS NOT PRESENT, VALUES OF PARAMETERS 14, 15, AND 16    -
CN              ARE SET TO ZERO.                                       -
CD                                                                     -
CN              THE NODAL OPTION IS INVOKED IN CARTESIAN GEOMETRY BY   -
CN              SPECIFYING GEOMETRY-TYPE SENTINELS 40 OR 44 ON THE     -
CN              A.NIP3 TYPE 03 CARD AND PROVIDING ANY ACCEPTABLE       -
CN              (E.G. DEFAULT) VALUES ON A.DIF3D TYPE 12 CARD.         -
CN                                                                     -
CN          *** THE CARTESIAN-GEOMETRY NODAL OPTION MAY NOT BE         -
CN              AVAILABLE IN ALL VERSIONS OF DIF3D. ***                -
C                                                                      -
CN              IT IS IMPORTANT THAT THE NUMBER OF FINE MESH PER       -
CN              REBALANCE MESH BE CHOSEN SUCH THAT THE AVERAGE         -
CN              REBALANCE MESH SPACING IS APPROXIMATELY 30 TO 40 CM IN -
CN              THE XY-PLANE.  THUS, FOR EXAMPLE, IF THE AVERAGE FINE  -
CN              MESH SPACING IS DELTA CM, THEN THE INTEGER INPUT IN     -
CN              COLS. 19-24 SHOULD BE BETWEEN 30/DELTA AND 40/DELTA.   -
C                                                                      -
CN              IF SLOW (OR DIVERGENT) ITERATIVE CONVERGENCE BEHAVIOR  -
CN              IS OBSERVED, THE NUMBER OF PARTIAL CURRENT SWEEPS      -
CN              SPECIFIED IN COLS. 25-30 AND 31-36 SHOULD BE INCREASED.-
C                                                                      -
C-------------------------------------------------------------------------

CEOF
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Appendix E. Description of Special TWODANT Input at ANL

Title Cards

The first card contains the number of title cards. It is formatted in I6. The number of cards may be zero.

Title cards are placed next.

Block I: Controls and Dimensions

All of the following except "maxlcm" and "maxscm" must be input for 2D models, even though some of the data are also in A.NIP3.

igeom= Geometry. 6/7/11 = X-Y/R-Z/R-THETA
ngroup= Number of energy groups for the input ISOTXS file
isn= Sn angular quadrature order (even number)
niso= Number of isotopes in ISOTXS
mt= Number of TWODANT materials. These correspond to our primary compositions (A.NIP3 type 14 cards). "mt" should be equal to "nzone" when the code is run with A.NIP3 input
nzone= Number of TWODANT zones. When the code is run with A.NIP3 input, there should be a one-to-one correspondence between TWODANT materials and TWODANT zones (mt=nzone)
im= Number of coarse spatial mesh intervals for the first dimension (from A.NIP3 06 or 09 cards)
it= Total number of fine spatial mesh intervals for the first dimension.
jm= Number of coarse spatial mesh intervals for the second dimension (from A.NIP3 06 or 09 cards)
jt= Total number of fine spatial mesh intervals for the second dimension
maxlcm= LCM container array size (optional, default=140000)
maxscm= SCM container array size (optional, default=40000)
t

Block II: Geometry

This block is not supplied since the geometry specifications are provided in A.NIP3.

Block III: Cross Sections

lib=isotxs
balxs= -1 = balance cross sections by adjusting absorption cross sections
0 = do not balance cross sections (default)
1 = balance cross sections by adjusting self-scattering cross section
t

Block IV: Mixing

Assign=matls
t

Block V: Solver Input

ievt= Calculation type: 0/1/2/3/4 = source/k-eff/alpha/concentration search/dimension search
isct= Legendre order of scattering
ith= 0/1 = direct/adjoint calculation
ibl= Left boundary condition: 0/1/3 = vacuum/reflective/white
ibr= Right boundary condition: 0/1/3 = vacuum/reflective/white
ibt= Top boundary condition: 0/1/2/3 = vacuum/reflective/periodic/white
ibb= Bottom boundary condition: 0/1/2/3 = vacuum/reflective/periodic/white
epsi= Conversion precision (default=0.0001)
iitl= Maximum number of inner iterations per group at first (default=1)
iitm= Maximum number of inners allowed when near fission source convergence (default chosen by code)
oitm= Maximum number of outer iterations (default=20)
fluxp= Final flux edit flag: 0/1/2 = no/isotropic/all moments
xsectp= Macroscopic cross section edit flag: 0/1/2 = no/principal cross section/all cross sections
fissrp= Fission rate edit flag: 0/1 = no/yes
sourcp= Source edit flag: 0/1/2/3 = no/unnormalized/normalized/both
angp= Angular flux edit flag: 0/1 = no/yes
raflux= Angular flux file (raflxm/aaflxm) edit flag: 0/1 = no/yes
trcor= Flag for the transport correction to cross sections on MACRXS file
diag = use diagonal transport correction
bhs = use Bell-Hansen-Sandmeier correction
cesaro = use Cesaro correction
no (or omit entry) = don't apply correction
norm= Normalization factor: 0/norm = no normalization/ normalize the fission source rate (ievt.ge.1) or the inhomogeneous source rate (ievt.lt.1) to "norm"
influx= Read flux start from the RTFLUX file: 0/1 = no/yes
insorst= Read source from interface file FIXSRC: 0/1 = no/yes

Block VI: Edit Input

pted= Fine space point edit flag: 0/1 = no/yes
zned= Zone edit flag: 0/1 = no/yes
igrped= Print option on energy groups: 0/1/2/3 = energy group totals only/broad groups only/broad groups only (same as 1)/both broad groups and totals (default =0)

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